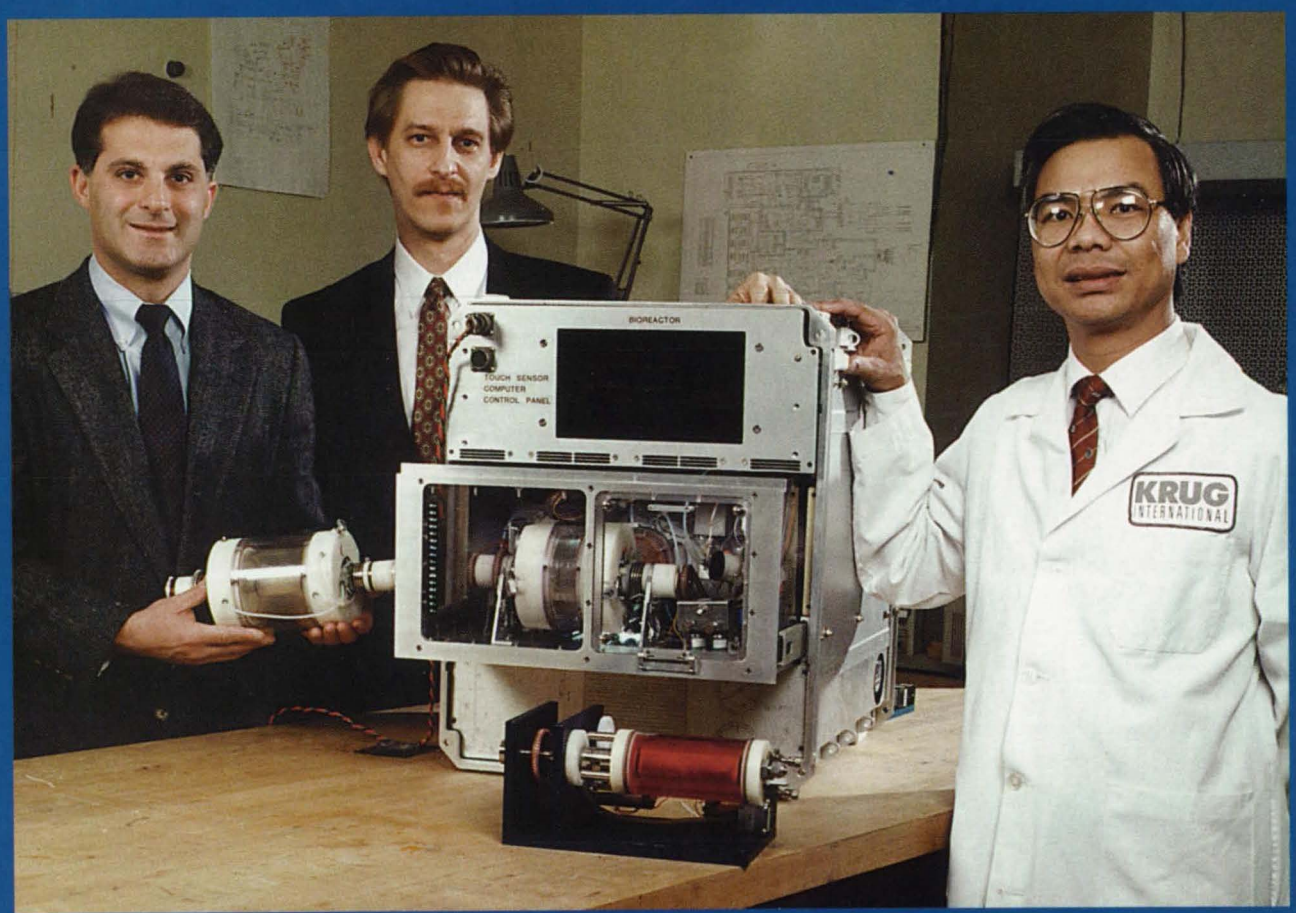
NASA Tech Briefs

Official Publication of
National Aeronautics and
Space Administration
Volume 16 Number 3

Transferring Technology
to Industry and
Government
March 1992

Inventors Of The Year



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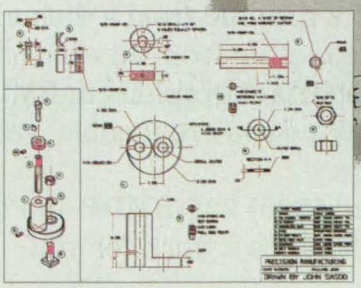

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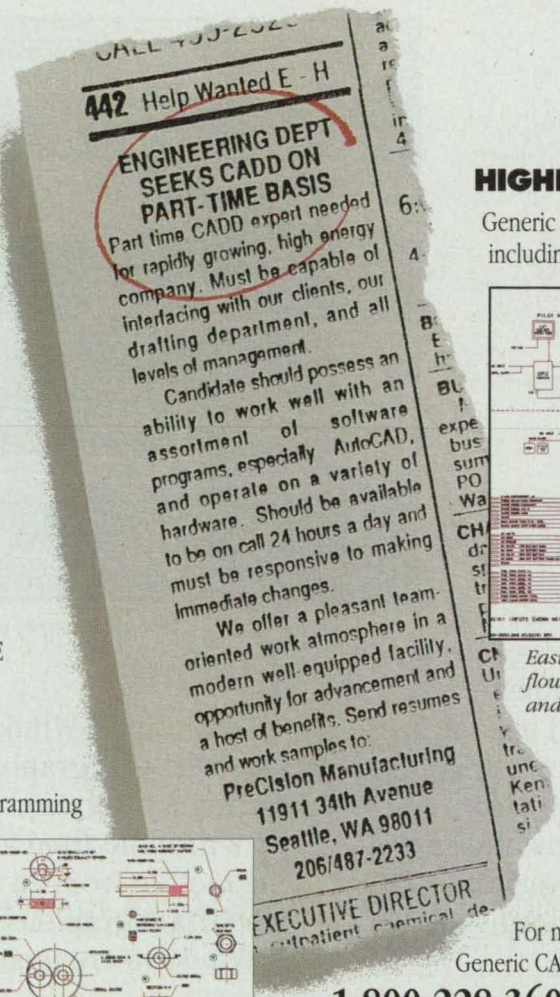

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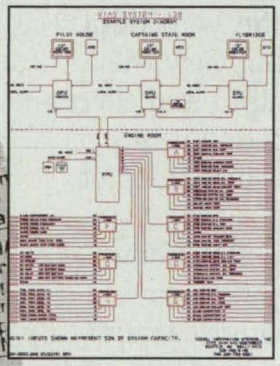

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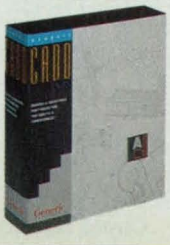

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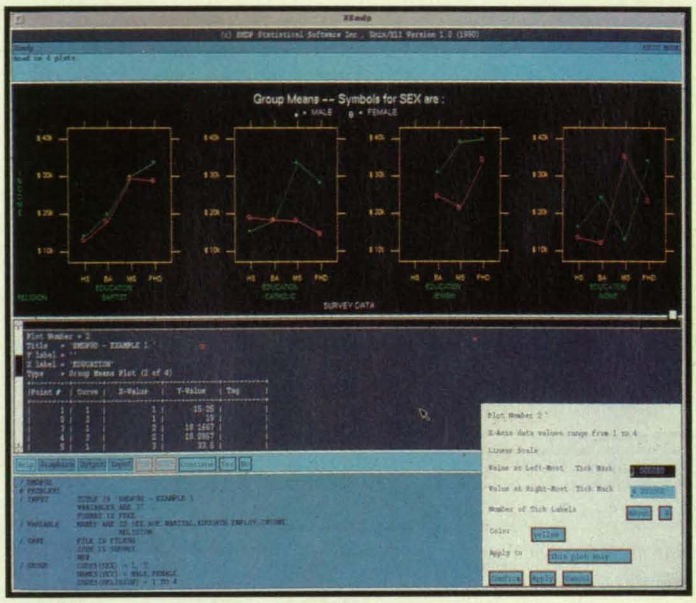

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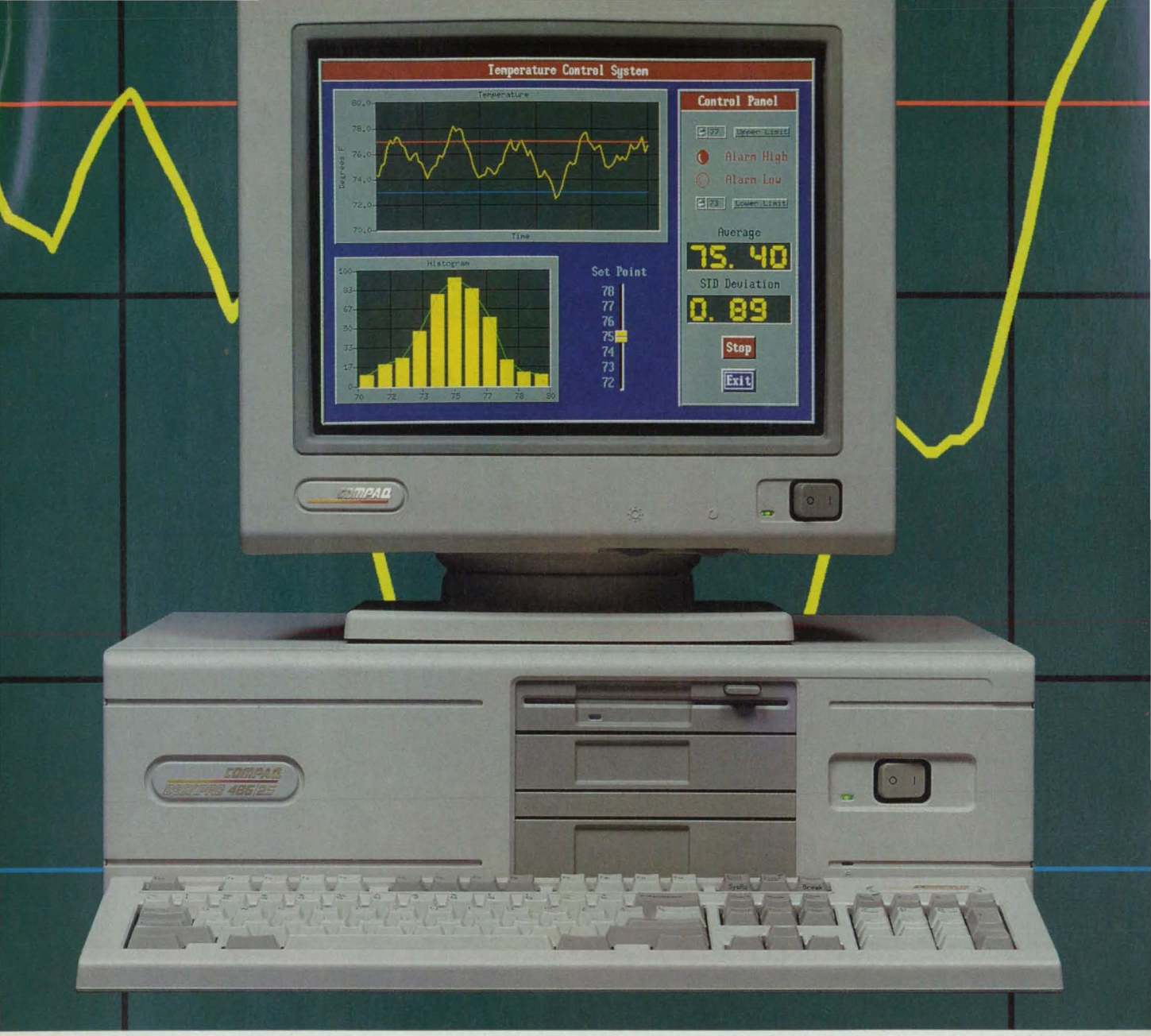

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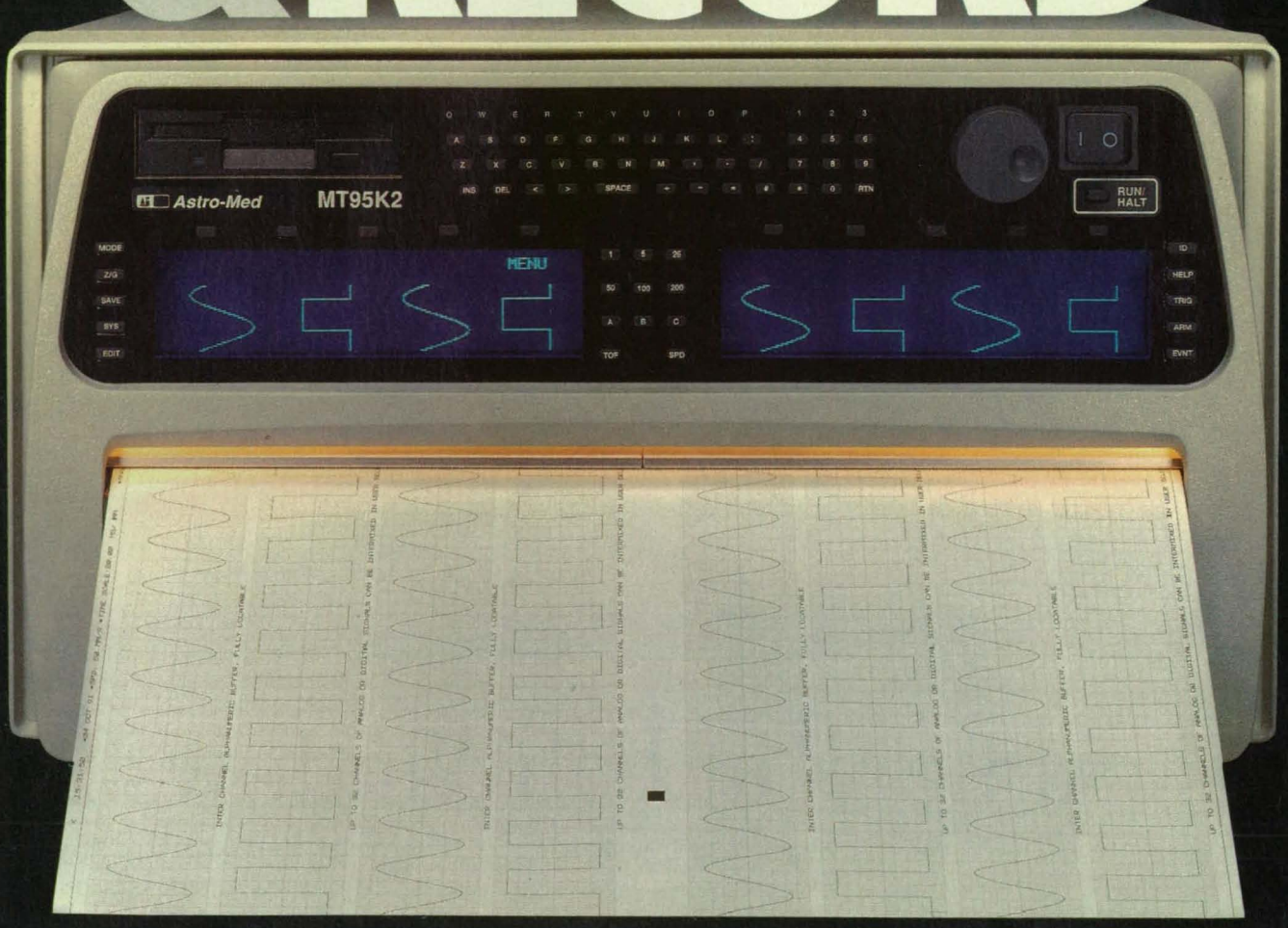

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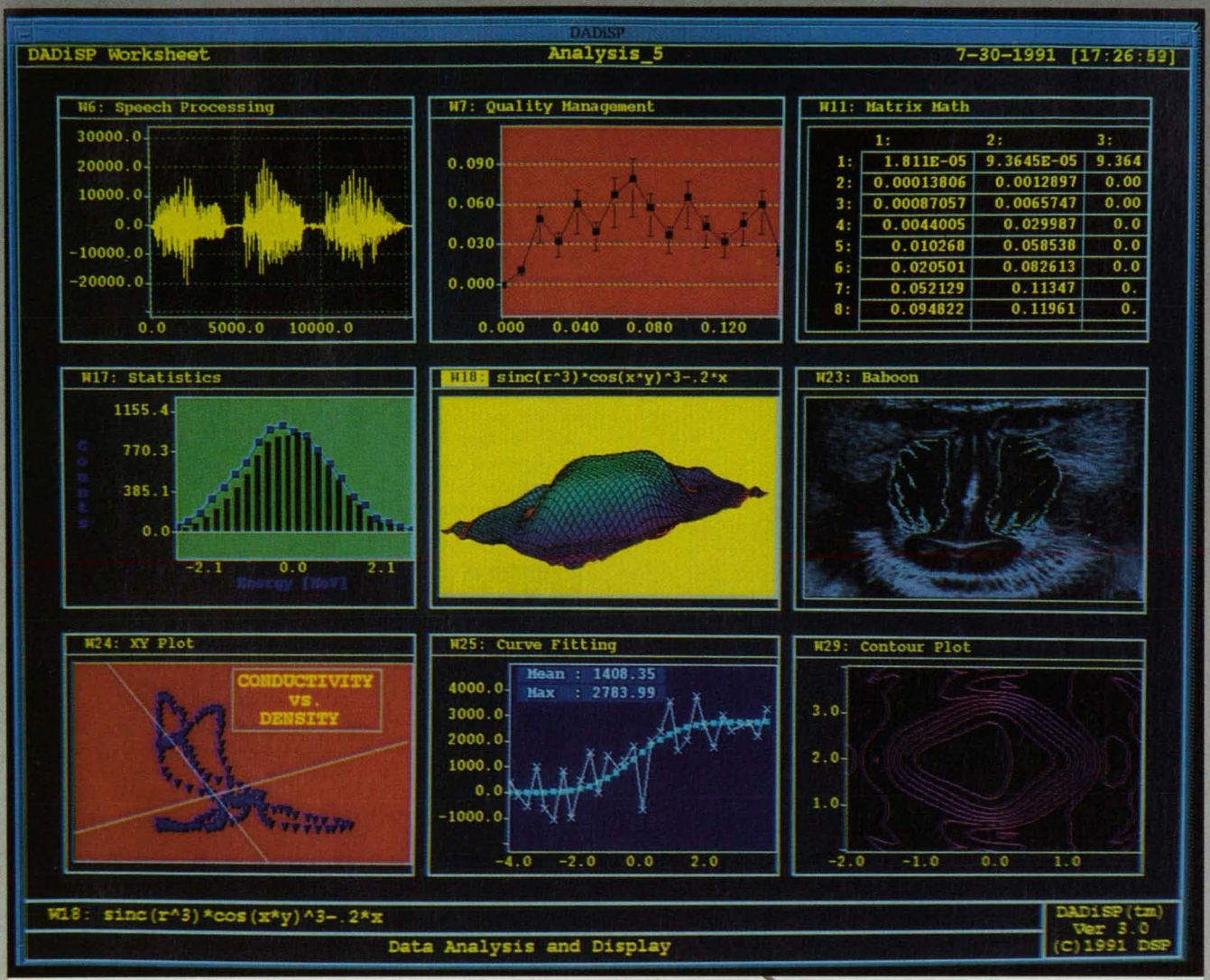

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March 1992
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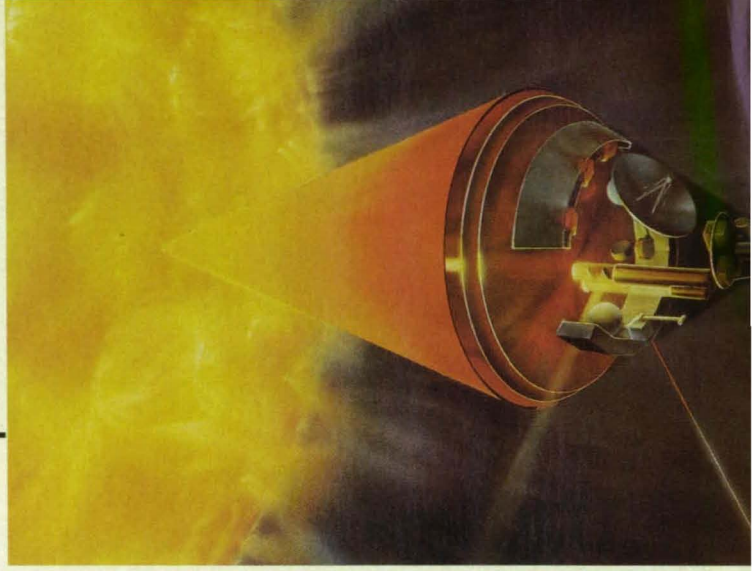


Illustration courtesy Jet Propulsion Lab

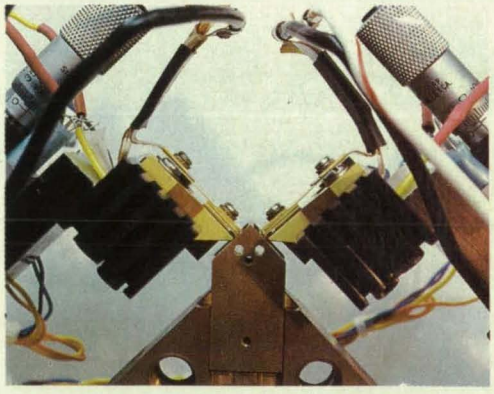
Engineers at Jet Propulsion Laboratory are designing the control system for a proposed spacecraft that would closely explore the Sun's surface and atmosphere. Called Starprobe, the craft would be launched on a trajectory that would take it within three solar radii of the Sun's surface, an altitude of about 1.3 million miles. See the technical brief on page 40.

SPECIAL FEATURES

TECHNICAL SECTION

DEPARTMENTS

On The Cover: David Wolf, Ray Schwarz, and Tinh Trinh (left to right) of the Johnson Space Center were named NASA's Inventors of the Year for developing a bioreactor useful for cancer and other medical research. They share the top inventor honors with a research team from Marshall Space Flight Center that created a lightweight ablative coating material for the space shuttle's solid rocket boosters. Turn to page 12.
(Photo courtesy Johnson Space Center)



Designed for simplicity, this laser head greatly improves the pumping efficiency of diode lasers. See our report on page 51.

Photo courtesy Goddard Space Flight Center

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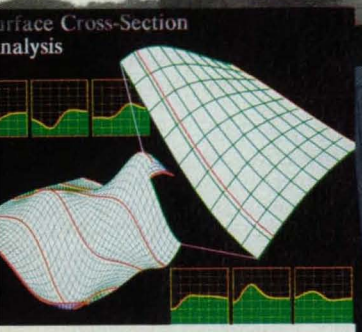

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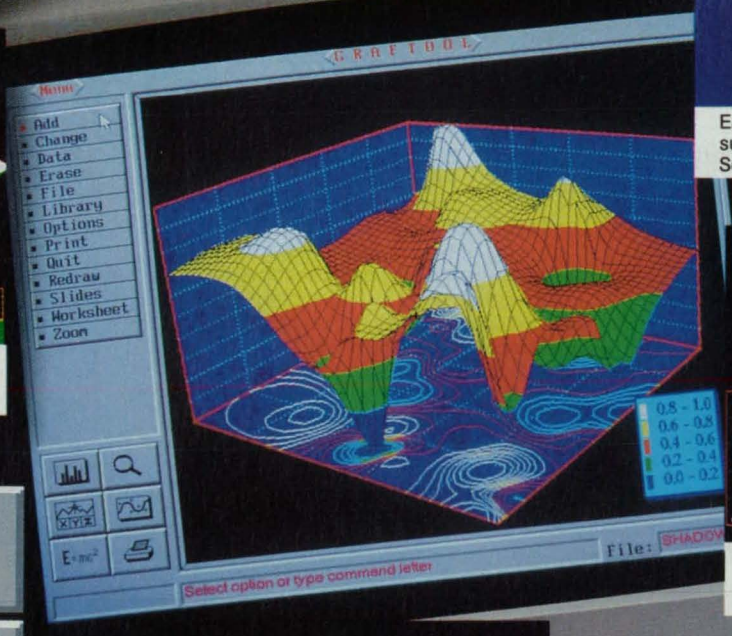

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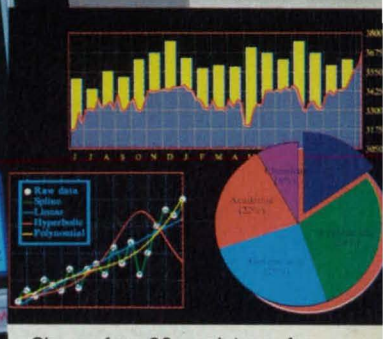

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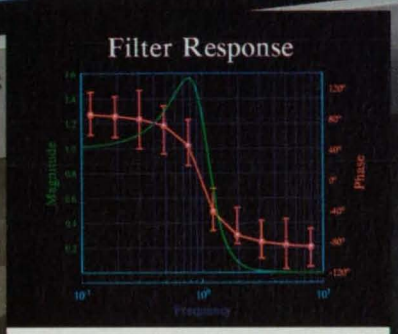

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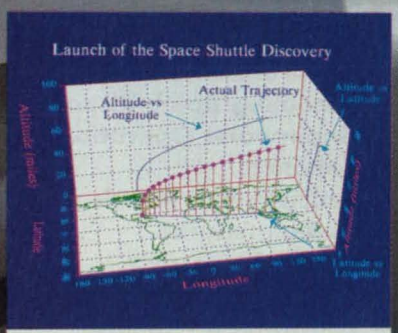

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NASA PATENTS

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Wet Spinning of Solid Polyamic Acid Fibers

(US Patent No. 5,023,034)
Inventors: **William E. Dorogy, Jr.** and **Anne K. St. Clair**

A new process generates solid aromatic polyamic acid and polyimide fibers from a wet gel using DMAc solutions of the acid derived from aromatic dianhydrides and diamines. By utilizing the interrelationship between coagulation medium and concentration, resin inherent viscosity, resin % solids, filament diameter, and fiber void content, the inventor has produced improved polyamic acid fibers. These fibers have excellent chemical resistance, high thermal stability, and tensile properties in the range of standard textile fibers.
Circle Reader Action Number 749.

Dual Strain Gauge Balance System for Measuring Light Loads

(US Patent No. 5,056,361)
Inventor: **Paul W. Roberts**

Mr. Roberts' invention measures light loads experienced by airfoil models during wind tunnel testing. The system employs two nonmetric panels that are connected to and extend toward each other from opposite sides of the wind tunnel, and a pair of strain gauge balances, each connected to one of the panels and the model. The balances have two sections, one for mounting a strain gauge bridge to measure normal force and pitching moment, and the other for mounting a bridge to measure axial force.
Circle Reader Action Number 753.

Silicon-Containing Electroconductive Polymers and Structures Made Therefrom

(US Patent No. 5,066,748)
Inventors: **Ganesan Nagasubramanian**, **Salvador DiStefano**, and **Ranty H. Liang**

The formation of an electropolymerized film on the surface of an anode yields composite structures with superior electrical and mechanical properties. Applications include electrostatic dissipation, corrosion suppression in metals, active electrodes for polymeric batteries, and aircraft structural materials that reduce radar cross section.
Circle Reader Action Number 745.

Permanent Wire Splicing by an Explosive Joining Process

(US Patent No. 5,064,111)
Inventors: **Laurence J. Bement** and **Anne C. Kushnick**

An apparatus for joining metallic wires permits repeatable and precise location of the explosive joint while reducing the amount of explosive required and minimizing noise damage to surrounding structures. Strands of each wire are joined in a mesh-like arrangement. A U-shaped metal strap slides over the strands and a standoff means is positioned between the two surfaces. Explosives drive the strap, causing a high-velocity, angular collision between the mating surfaces. This creates surface melts and bonding that results in electron-sharing linkups.
Circle Reader Action Number 747.

Processing for Maximizing the Level of Crystallinity in Linear Aromatic Polyimides

(US Patent No. 5,061,783)
Inventor: **Terry L. St. Clair**

Linear aromatic polyimides have exceptional thermal and oxidative stabilities but poor softening/flow properties. Mr. St. Clair of NASA's Langley Research Center has developed a process that maximizes the crystallinity in a linear polyimide without degrading its molecular weight. First, the polyimide is treated with an amide-containing solvent having an aprotic organic base, then dehydrated with an organic agent such as acetic anhydride. This results in polyimides that can be melted at moderate temperatures, affording adequate flow for production of adhesives, molding powders, and matrix resins.
Circle Reader Action Number 741.

Birefringent Filter Design

(US Patent No. 5,062,694)
Inventor: **Clayton H. Bair**

A novel birefringent filter design increases wavelength selectivity in broad-band emission lasers while avoiding the degradation in optical quality associated with the thin plates of standard filters. In the new design, the thickness of the plates is a nonuniform, integral multiple of the difference between the thicknesses of the two thinnest plates. The resulting wavelength selectivity is equal to that of a conventional filter in which the thinnest plate has a thickness equal to this difference. Applications include atmospheric remote sensing, in which a single wavelength must be selected from within the continuous spectral output range.
Circle Reader Action Number 751.

Low-Cost, Formable, High-Temperature Superconducting Wire

(US Patent No. 5,049,539)
Inventor: **James L. Smialek**

Standard methods for producing ceramic superconductors involve sintering, hot pressing, or hot isostatic pressing of ceramic oxide powders, all of which preclude the formation of complex articles such as long, fine wire. The process developed by Mr. Smialek partially oxidizes a copper alloy containing low levels of rare-earth and alkaline-earth dopants. Upon oxidation at high temperatures, the superconducting oxide phases are formed as highly compliant ceramic films that yield wire configurations instead of just bulk solids.
Circle Reader Action Number 743.

For more information about the inventions described above, including licensing procedures, circle the corresponding number(s) on the Reader Action Request Form (page 99). ❑

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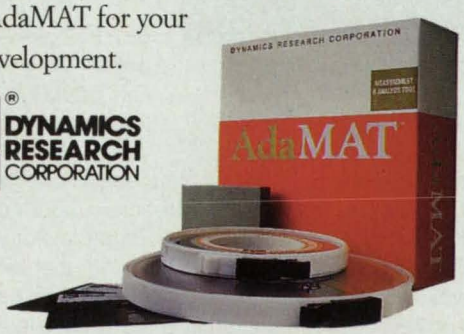

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Circle Reader Action No. 601

NASA Inventors Of The Year

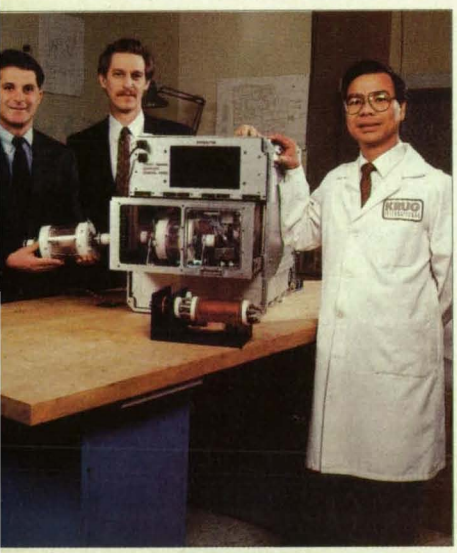
Johnson, Marshall Researchers Share Top Honors

It's a tie. For the third time in the 17-year history of NASA's Inventor of the Year competition, the agency has named two winners of its prestigious award. Representing the Johnson Space Center and Marshall Space Flight Center, they were chosen for disparate but equally important innovations: one a cell growth system that aids medical research, the other a super-strong coating technology that improves the safety and efficiency of space flight. Following is a look at the winners and the other five finalists, all of whose inventions were patented and/or commercially available in 1991. They represent the best of NASA, and the best of American ingenuity.

The Winners

Ray P. Schwarz, David A. Wolf, and Tinh T. Trinh
Johnson Space Center

Invention: Rotating Bioreactor Cell Culture Apparatus



Left to right: David Wolf, Ray Schwarz, and Tinh Trinh

A bioreactor this trio developed for space experiments is proving a boon to cancer research and may one day grow transplantable human tissue. The system produces high-density cell cultures and many cell types that will not otherwise grow outside the body. It provides a low-shear, low-turbulence environment needed to grow delicate mammalian cells.

"It's like a 3D petri dish that grows a lot of tissue very rapidly," said David Wolf, an astronaut and space physician. Mr. Wolf shares the award with Ray Schwarz, a biomedical engineer and former supervisor of Johnson's Bioreactor Laboratory, and Tinh Trinh, a technician with the center's Biotechnology Group.

The Johnson team began by studying the effects of microgravity on cell tissue cultures while also investigating means to protect cell cultures during space shuttle launchings and landings. They determined that conventional ground-based culture systems interfered with the three-dimensionality of cell structure, without which cells cannot form higher-order tissue structures. In the process of simulating zero-gravity biosynthesis, they developed a bioreactor that grows cells exceedingly well on Earth.

Tissues grown in the bioreactor are larger and exhibit many structural and chemical characteristics of normal tissue, suggesting the system could grow transplantable human tissue and tissue culture alternatives to animal research subjects. Medical researchers currently are using the system to investigate the growth and treatment of brain and colon malignancies. It also is helping to improve tissue culture production of drugs to dissolve blood clots and treat various diseases. Moreover, cultures of lung, liver, small intestine, and cartilage tissue are providing insight into human growth processes.

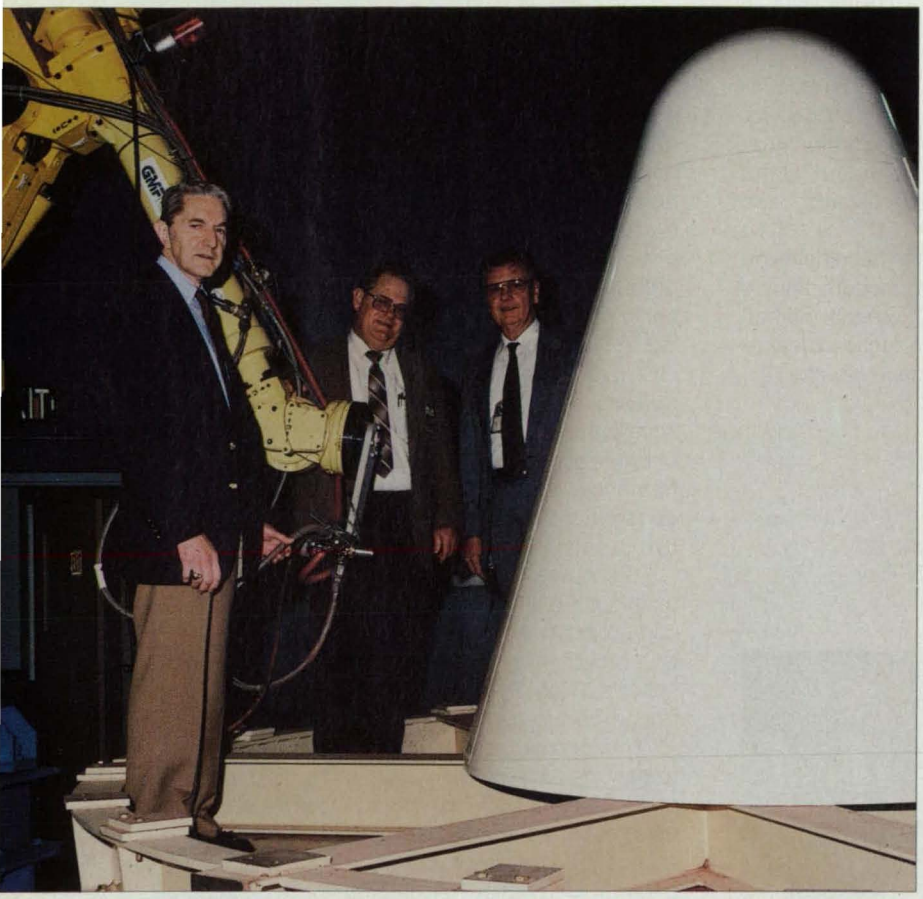
The bioreactor comprises inner and outer co-rotating cylinders, with the space between them completely filled with liquid medium. The medium is rotated at a low speed about a horizontal axis, moving as a solid body and thus avoiding the damaging shears created when fluid is moved with stirrers or bubble action. The inner cylinder, which rotates on a shaft synchronous with the movement of the entire vessel, has a porous wall that allows oxygen and nutrients necessary for cell growth to diffuse in and out.

Mammalian cells must attach themselves to an object in order to duplicate. The addition of 50-150 micron carrier beads to the chamber provides maximum surface area for cell attachment.

This award marks the second in a row for NASA Johnson. In 1991, Leo Monford won for his Targeting and Reflective Alignment Concept, a highly-accurate docking alignment system. As with Monford, the bioreactor's development team will be NASA's nominee to the National Inventor of the Year competition, the winner of which will be announced in April.

William G. Simpson, Max H. Sharpe, and William E. Hill
Marshall Space Flight Center

Invention: Sprayable Lightweight Ablative Coating



Left to right: William Hill, Max Sharpe, and William Simpson

Solid rocket boosters (SRBs) returning to Earth strike the ocean hot and with tremendous force. The Marshall invention makes it easier to refurbish, and thereby recycle, the boosters after the highly corrosive reentry. Dubbed MSA-2, the coating is a direct descendent of the MSA-1 protectant used on SRBs for more than 25 space shuttle flights.

"It all started with MSA-1," said Mr. Simpson, who helped develop the original ablator. "We tested several coatings and found this was the best one to improve upon."

MSA-2 is lighter than its predecessor, has improved flexibility and thermal properties, and features a stronger char layer during ablation. Because it is stronger, MSA-2 is also safer than MSA-1, pieces of which are believed to have broken off and caused tile damage on the orbiter.

The coating is a carefully balanced mixture of phenolic microballoons, hollow glass spheres, glass fibers, ground cork, a flexible resin binder, and an activated colloidal clay. Improvements include replacing 15 percent of the phenolic microballoons in MSA-1 with an equal volume of ground cork to serve as an internal stress conditioner. Flexibilized epoxy resin is substituted for the original epoxy-modified polyurethane binder. The clay helps keep everything in suspension, while use of more environmentally-safe solvents reduces toxicity and fire hazard.

The new coating has replaced the old on all shuttle SRBs and is now flown on every mission. It can be used on the aft skirts, eliminating the expensive and time-consuming hand labor previously required to apply layers of cork.

MSA-2 can be robotically sprayed onto the SRBs in layers up to 1/2" thick. The layer cures without developing shrinkage cracks, as occur at the same thickness with MSA-1. A new mobile robot strips the coating automatically. "You can put it on cheaply and, just as important, take it off cheaply before refurbishment," said Mr. Sharpe.

The three co-inventors worked on the coating in Marshall's Materials and Processes Laboratory. Mr. Sharpe is currently chief of the lab's Process Engineering Division. A chemical engineer, he joined Marshall in 1960 and participated in the development of many US rockets and space vehicles, including the Saturn V, Redstone, Jupiter-C, Juno-II, and the space shuttle. Mr. Simpson's career with NASA began in 1963, and he now works as a senior materials engineer for USBI's Florida operation at Kennedy Space Center. Dr. Hill, who developed materials for the Saturn program, worked at the Marshall Center from 1964 to 1990, when he retired from his position as deputy chief of the Process Engineering Division.

The researchers expect there will be an MSA-3 with improved temperature resistance that will utilize water-based solvents. "Materials don't care what they're floating around in—once it dries, the solvent is gone," said Mr. Simpson, who anticipates little difficulty in shifting to even safer solvents.

1992 Award Finalists

Leonard A. Haslim
Ames Research Center

Invention: Airborne Rescue System

A helicopter's ability to hover makes it a useful tool for rescue operations at sea. One drawback, however, is the powerful downwash created by its main rotor, which can endanger the intended rescuee. Mr. Haslim, program manager for Ames' Advanced Plans and Programs Office, has designed a telescoping boom that improves helicopters' efficacy by extending the rescue cable out in front of the craft and beyond the radius of the main

rotor. This allows the pilot to maintain visual contact with the rescuee and to precisely control the positioning of the cable, while minimizing downwash.

The boom releases the rescuee's weight before it can impose undesirable torques on the helicopter. As the helicopter ascends with the rescuee and tension on the cable increases, the line is progressively stripped from the boom's eyelets, dropping to the main hoist where it can be reeled in by a motorized winch.

Haslim, who won top inventor honors in 1988 for an electro-expulsive aircraft deicer and was nominated again in 1989 for a lightweight, fireproof seat cushion, saw an opportunity to save lives with his latest innovation. "I had heard about downed aviators going through hell while being rescued," said Haslim, a former Navy fighter pilot.

The system weighs only 60 pounds and can be installed in three minutes. It could be used to rescue people from sinking ships, high-rise fires, and mountainsides. Potential spinoff applications of the boom's extension and retraction mechanism include in-situ erection of telescopic space structures.

Richard B. Hoover
Marshall Space Flight Center

Invention: Variable Magnification, Variable Dispersion Glancing Incidence Imaging X-Ray Spectroscopic Telescope

Mr. Hoover has designed an x-ray telescope capable of high-spatial-resolution imaging of solar and stellar x-ray and extreme ultraviolet radiation sources at precise spectral wavebands. "This scope answers a particular need for simultaneous high-resolution spectroscopy and imaging," said Hoover, an astrophysicist in the Marshall Center's Solar-Terrestrial Physics Division.

Designed for operation on the space shuttle or an orbiting space station, the telescope features a series of diffraction grating mirrors, reflecting different wavelengths, mounted on two or more rotatable carriers to obtain multiple magnifications and fields of view.

It is especially useful for studying the solar atmosphere, enabling physicists to distinguish thin atmospheric layers. It can be used to determine temperature, electron density, and x-ray flux of x-ray-emitting plasma. The images allow precise determination of the x-ray source's chemical composition.

Billy T. Upchurch, Irvin M. Miller, Erik J. Kielin, Patricia M. Davis, David R. Schryer, Kenneth G. Brown, and John D. Van Norman (dec.)
Langley Research Center

Invention: Catalyst for Carbon Monoxide Oxidation

Left to right: Irvin Miller, Kenneth Brown, Billy Upchurch, Patricia Davis, David Schryer, and Erik Kielin

Langley's nominees have produced oxidation crystals for the recombination of CO and O_2 dissociation products formed during CO_2 laser operation. Both the loss of CO_2 and the buildup of O_2 significantly degrade laser performance. CO_2 regeneration allows lasers to operate continuously in a closed-cycle, as would be necessary for extended use in space.

The novel catalyst includes platinum, a reducible metal oxide with multiple valence states, for example SnO_2, and a compound that can bind water, such as silica gel. Its efficient CO_2 recycling will allow the laser aboard NASA's Laser Atmospheric Wind Sounder—intended to measure global winds from orbit—to operate continuously for five years.

The invention can be applied to any CO_2 laser, as well as to gas masks and low-temperature air purification in closed environments such as submarines. It can remove CO and other automobile exhaust gas constituents during and shortly after engine start-up, before the catalytic converter is hot enough to function. According to Dr. Upchurch, a senior research scientist, this type of catalyst could prove useful for species other than CO_2.

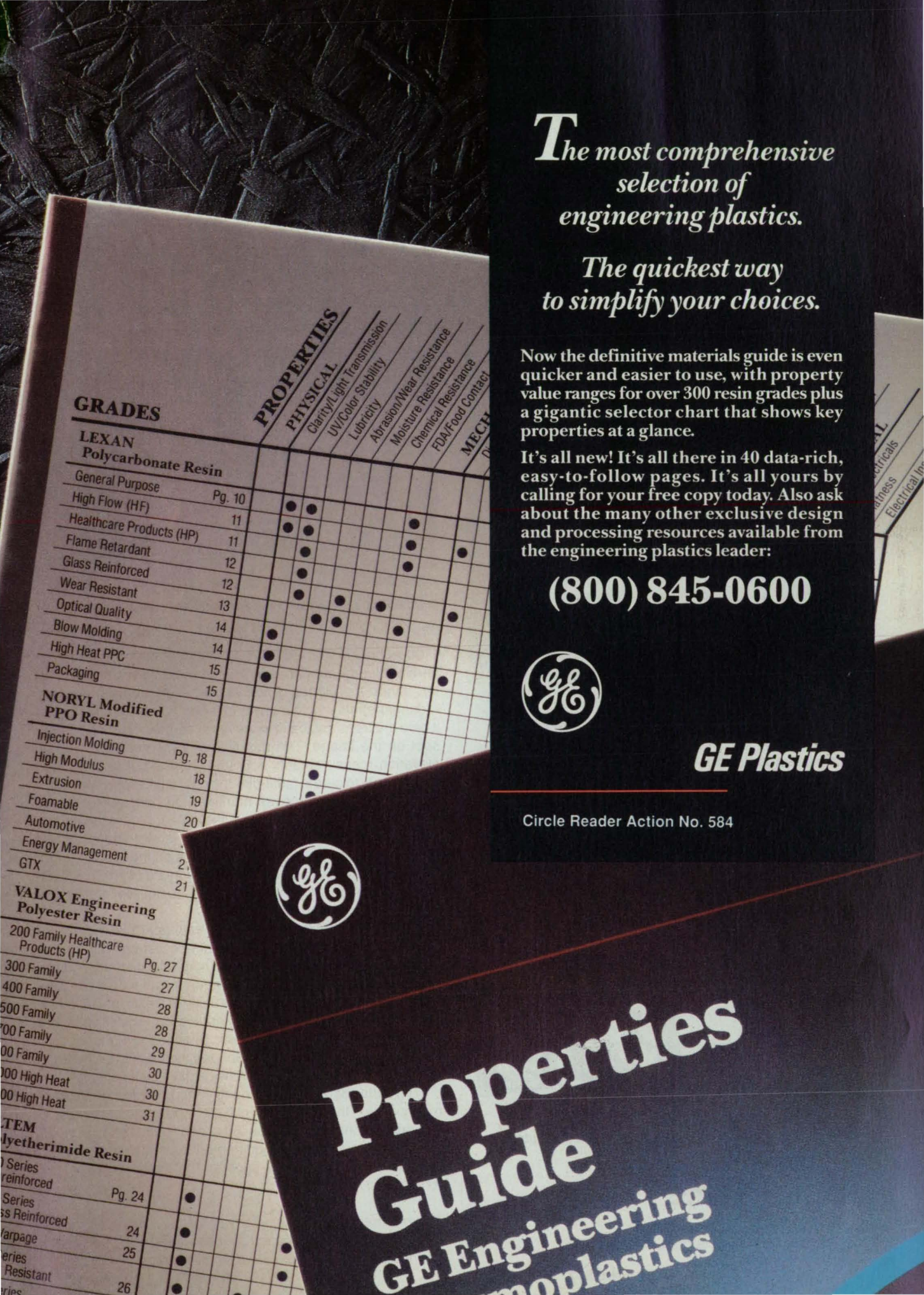
Mary Jo W. Shalkhauser, Wayne A. Whyte, Jr., and Scott P. Barnes
Lewis Research Center

Invention: Real-Time Data Compression of Broadcast Video Signals

These researchers collaborated on a compression encoder/decoder (CODEC) that compresses NTSC composite color television signals for efficient transmission in a digital format. It preserves the original image quality with a nearly 5:1 reduction in transmitted data.

Encoding is accomplished by prediction of the sampled video through a 2D differential pulse code modulation (DPCM) process. Improving on

Mary Jo Shalkhauser and Wayne Whyte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conventional DPCM-based CODECs, the invention employs a nonadaptive predictor to improve the edge quality in the reconstructed pictures. Another innovation is the use of a multilevel Huffman encoder to significantly reduce the bit/pixel ratio.

The invention is "easy to implement, uncomplicated, and works in real time," said Ms. Shalkhauser, who, like her co-inventors, is an electrical engineer. It can be applied wherever efficient transmission of high-quality video signals is needed.

Marc L. Imhoff
Goddard Space Flight Center

Invention: Topographic Terrain Models Generated Using Synthetic Aperture Radar and Surface Level Data

Marc Imhoff (center) with his Bengali field team.

A technique that employs synthetic aperture radar to determine flood boundaries in foliage-covered regions earned Mr. Imhoff the Goddard nomination. The airborne or orbital radar penetrates the canopy and "sees" water by reflecting off it onto the trees and back to the radar source, creating a bright spot on the image. The radar data is merged with surface elevation measurements acquired from airborne or ground instruments to create multi-dimensional digital terrain models.

The invention improves markedly on prior aerial survey instruments, which could not see through forest canopy. Obtaining detailed topographical data therefore necessitated entering an area to take measurements on the ground, often a long and tedious task. Further, many areas of interest, such as the Amazon basin and Mekong delta, are not readily accessible to ground survey.

Topographical images acquired with aperture radar yield clues to the formation and health of ecosystems throughout the tropics and subtropics. Surface hydrology factors, such as water level dynamics and flood frequency affect the productivity of wet coastal forests and the utility of the soils. Mr. Imhoff developed the technique while leading an expedition in the Peoples Republic of Bangladesh. Studies there focused on the Sundarbans forest in the Ganges river delta, a 12- to 15-meter-tall forest that is flooded twice daily by tidal action.

The radar data can help identify the breeding grounds of mosquitoes—the source of malaria and other diseases. It can also monitor trace gas flux, sea level rising, ground subsidence, nutrient transport from a forested area into a river, and localized phenomena such as the health of mangrove forests and fisheries. ❑

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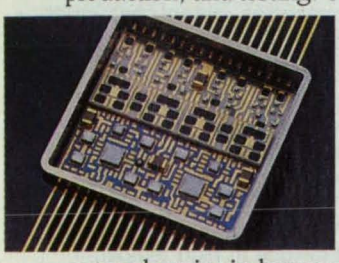

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New Product Ideas

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New Cross-linkable Polyimides

Methyl groups cross-link in air at 275 °C or upon ultraviolet irradiation to form insoluble polyimides. These máterials can be useful as high-temperature coats for printed-circuit boards, for photoresist applications, and possibly for printing and membrane applications. Other uses may be as films, adhesives, and composite matrices.
(See page 60)

Optical Detection of Ice on Helicopter Rotor

A proposed system would use a laser diode aimed at the leading edge of a helicopter rotor blade. Ice would alter the polarization of the reflected laser beam. Three receivers and a microprocessor would detect the difference and warn the pilot of the icing hazard.
(See page 44)

Broadband Active Antenna

A circuit enhances the current induced in the search coil by an alternating magnetic field. This arrangement increases the effective area of the coil beyond its geometric area, significantly broadening the coil frequency response.
(See page 26)

Electronic Control of Slow Rotations

A digital/analog circuit controls the angular position and the speed of rotation of a motor shaft with high precision. Potential applications of this circuit or its modified version include precise control of robotic manipulators, translation mechanisms of crystal-growing furnaces, hands on mechanical clocks, and other rotating mechanisms.
(See page 38)

Polyethylene Glycol Propionaldehydes

This new class of compounds is stable in water and reactive toward amines. The compounds and their derivatives hold promise in such biotechnical and biomedical applications as partitioning of two phases in aqueous media; immobilization of enzymes, antibodies, and antigens; modification of drugs; and preparation of protein-rejecting surfaces.
(See page 59)

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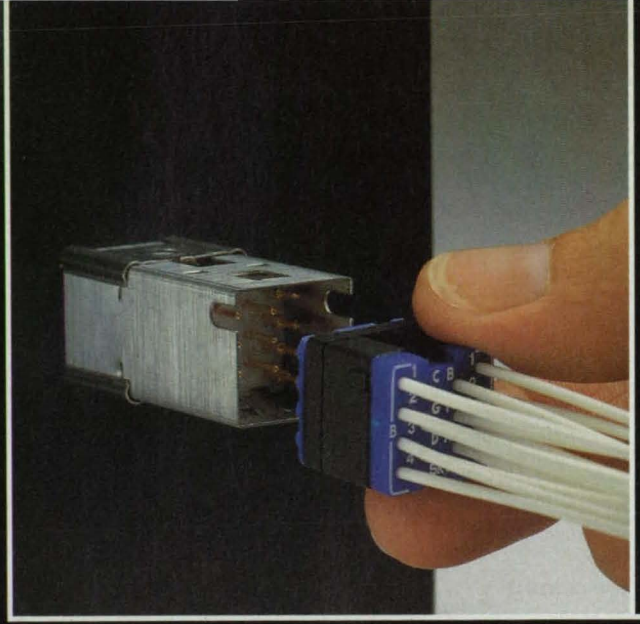
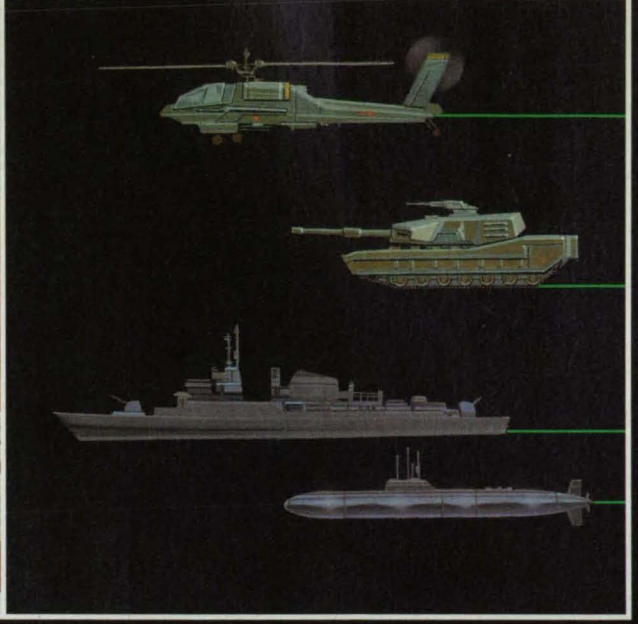
(See page 71)





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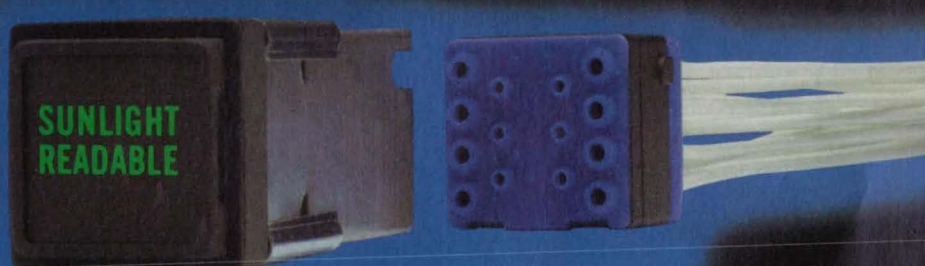

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If you represent a public sector organization with a particular need, you can contact NASA's Application Team for technology matching and problem solving assistance. Staffed by professional engineers from a variety of disciplines, the Application Team works with public sector organizations to identify and solve critical problems with existing NASA technology. **Technology Application Team, Research Triangle Institute, P.O. Box 12194, Research Triangle Park, NC 27709; *Dr. Doris Rouse, Director,* (919) 541-6980**

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If you need further information about new technologies presented in NASA Tech Briefs, request the Technical Support Package (TSP). If a TSP is not available, you can contact the Technology Utilization Officer at the NASA Field Center that sponsored the research. He can arrange for assistance in applying the technology by putting you in touch with the people who developed it. If you want information about the patent status of a technology or are interested in licensing a NASA invention, contact the Patent Counsel at the NASA Field Center that sponsored the research. Refer to the NASA reference number at the end of the Tech Brief.

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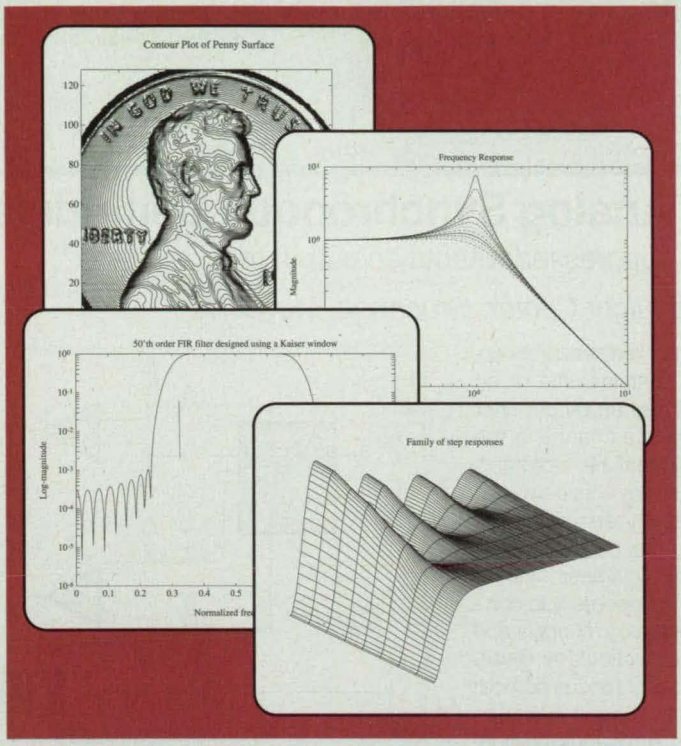

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Improved Analog Synchronous Demodulator

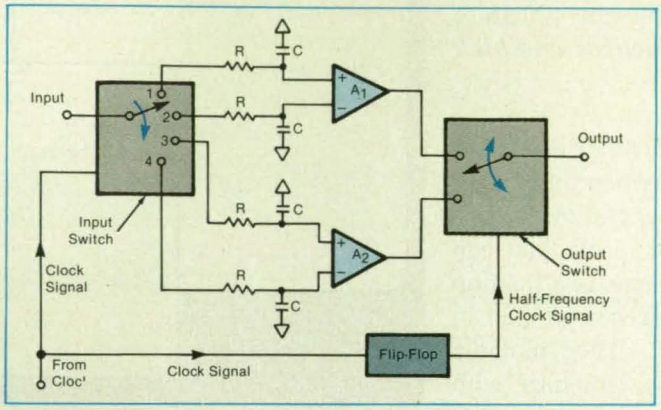
Output ripple is suppressed without an output filter.

Goddard Space Flight Center, Greenbelt, Maryland

The output of an improved synchronous-demodulator circuit contains little or no ripple, yet does not need an output filter and responds rapidly to a change in the level of the detected signal. Heretofore, in synchronous demodulators, these two features have been mutually exclusive: one could low-pass-filter the output signals to suppress ripple, but low-pass filtering slowed the response. The necessity to compromise between suppression of ripple and speed of response is particularly disadvantageous where a synchronous demodulator is part of a control circuit, because ripple contributes an erroneous component to a control signal, while slow response can give rise to unstable or ineffective control.

A synchronous demodulator is used to detect a periodic signal that may be "buried" in noise. In essence, a synchronous demodulator includes an amplifier, the gain of which is alternated between a positive value and a negative value of equal magnitude by a signal that is known to be synchronous with the periodic signal to be detected. Thus, its effect on the desired periodic component of the noise-corrupted input is that of an amplifier followed by a full-wave rectifier.

The figure illustrates one version of the improved synchronous demodulator. The switch symbols represent electronic switching circuits that include solid-state electronic pass/no-pass elements like junction field-effect transistors or complementary metal oxide/semiconductor transistors. Under control of the synchronizing clock signal, the input switch feeds the noise-corrupted input to each of terminals 1 through 4 for half a clock cycle in sequence. (The full sequence takes two clock cycles.) During each half cycle while it is being fed in through one of these terminals, the input signal is low-pass-filtered and thereby effectively averaged by the combination of resistor R and capacitor C, which are typically chosen so that the filter time constant RC ≈ 10 times the clock period.



The **Improved Analog Synchronous Demodulator** uses input filtering, differential amplification, and synchronized switching in such a way that output ripple is suppressed without the need for an output filter, and the output can respond rapidly (within a clock cycle) to a change in the level of the demodulated signal.

Differential amplifiers A_1 and A_2 are identical and have input impedances much greater than that of R. Thus, when the input is not being fed into a given RC filter, the capacitor C in that filter acts as a memory element, storing the average of the signal that it received during its most recent input half clock cycle. During the full clock cycle when input is not being fed to terminals 1 and 2, the output of differential amplifier A_1 thus becomes, in effect, a doubled version of the synchronously detected signal, smoothed by averaging over the previous clock cycle during which it received input. Similarly, the output of differential amplifier A_2 becomes the desired output during the next clock cycle, when the input is not being fed to terminals 3 and 4. To pass the desired output signal to the external circuits, the output switch makes contact with the output terminals of A_1 and A_2 on alternate full clock cycles.

This work was done by John F. Sutton of **Goddard Space Flight Center**. *For further information, Circle 7 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 20]. Refer to GSC-13179.

Digital Synchronous Demodulator

The digital version offers greater speed, precision, and reliability.

Goddard Space Flight Center, Greenbelt, Maryland

The digital synchronous demodulator offers further advantages over the improved analog synchronous demodulator described in the preceding article (GSC-13179). Although the improved analog synchronous demodulator, in turn, offers advantage over conventional analog synchronous demodulators, its output can include errors caused by (1) imprecise matching of the differential amplifiers, resistors, and capacitors, (2) thermal drifts in the electrical characteristics of these components, (3) switching transients, and (4) the charge-injection effect in the capacitors. In addition, although the improved analog synchronous demodulator can respond faster to a change in the level of the detected signal than can a conventional analog synchronous demodulator, the speed of its response is still limited by the characteristic time of its resistor•capacitor input filters. The digital synchronous demodulator largely overcomes these major remaining

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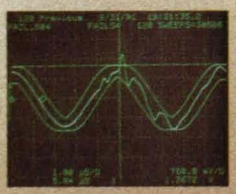

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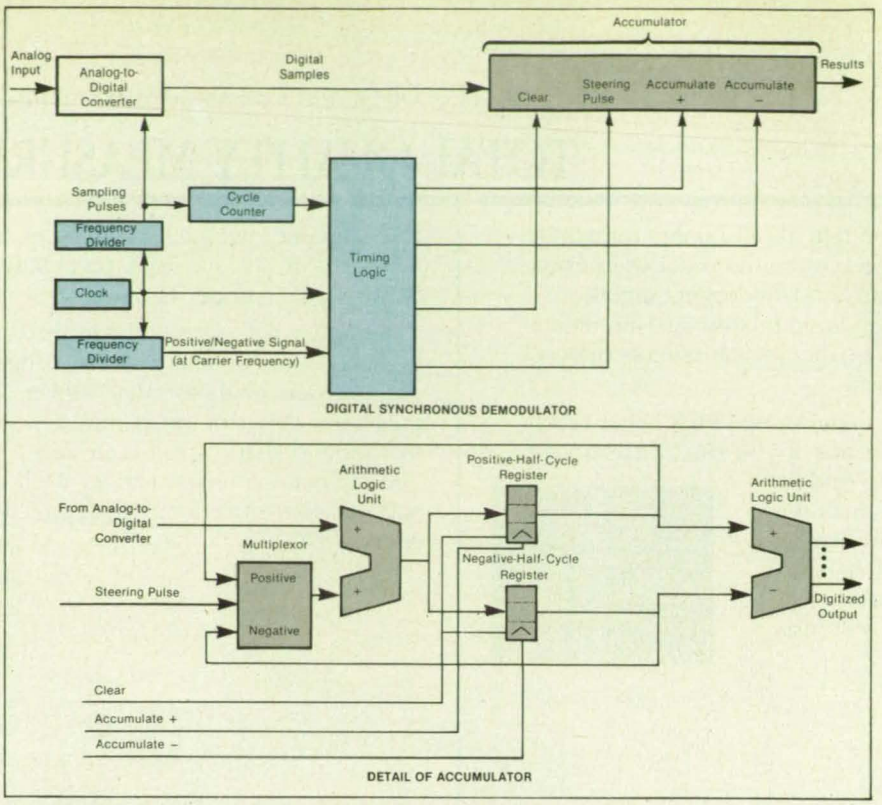
disadvantages of the improved analog synchronous demodulator.

The subsystems of the digital synchronous demodulator include an analog-to-digital converter, an accumulator, timing logic, a cycle counter, a clock (master oscillator), and two frequency dividers (see figure). The clock is the same one that is used to generate the periodic sinusoidal (carrier) signal to be detected, and here the clock signal is passed through one of the frequency dividers to generate the positive/negative signal, which is a square wave that is positive or negative when phase of the carrier is 0° to 180° or 180° to 360°, respectively. The clock signal is also passed through another frequency divider to generate the sampling pulses. In a typical design, 512 samples are taken during each carrier cycle.

The input signal is processed by the analog-to-digital converter at the sampling-pulse rate, and the digitized samples are sent to the accumulator. The accumulator includes two registers. Operating under the overall synchronizing control of the clock signal, the timing logic causes the accumulator to sum all the digitized samples taken during the positive half cycles of a measurement period in one register and to sum all the digitized samples taken during the negative half cycles of a measurement period in the other register. A typical measurement period might be 16 carrier cycles.

A measurement period begins at the first sample in the first positive half carrier cycle that occurs after a "clear" signal. The "clear" signal sets the contents of the cycle counter and registers at zero. The measurement period ends when the count in the cycle counter reaches the designated number; e.g., 16. The "clear" signal can be generated automatically and periodically by another counter (not shown) or manually. At the end of the measurement period, a second arithmetic logic unit in the accumulator computes the difference between the contents of the positive- and negative-half-cycle accumulators. This difference is the desired synchronously demodulated output.



The **Digital Synchronous Demodulator** suppresses ripple and other spurious outputs. Unlike the improved analog synchronous demodulator, it does not depend on precise matching of active and passive analog components.

Unlike in the improved analog synchronous demodulator, there are no variations in input offsets or in the gains of analog differential amplifiers. The accumulation of large numbers of samples reduces the amount of error contributed by the analog-to-digital converter and results in a higher precision measurement. The speed of response is, of course, limited by the duration of the measurement period, even though it is no longer limited by resistor-capacitor response time. One could, of course, decrease the measurement period to increase speed, albeit at the price of increased sampling error and bandwidth.

This work was done by Christopher E. Woodhouse of **Goddard Space Flight Center**. *For further information, Circle 82 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 20]. Refer to GSC-13273.

Pseudomorphic $In_xGa_{1-x}As$ Surface-Emitting Lasers

Light can be deflected out through the substrate, if necessary.

NASA's Jet Propulsion Laboratory, Pasadena, California

Solid-state lasers of a new type contain pseudomorphic $In_{0.15}Ga_{0.85}As$ single-quantum-well (SQW) active layers sandwiched between thinner layers of GaAs that, in turn, are sandwiched between graded-index-of-refraction separate-confinement-heterostructure (GRINSCH) layers of $Al_xGa_{1-x}As$. These lasers can emit edgewise as other solid-state lasers can, or they can be made to emit perpendicularly to their surfaces by use of integrated 45° beam deflectors that deflect edge-emitted light (see figure).

The surface-emitting feature makes these lasers particularly suitable for incorporation into optoelectronic integrated circuits that implement optical interconnection and parallel processing of data. The lasers of this class offer an advantage over similar quantum-well lasers based on $Al_xGa_{1-x}As$: The GaAs substrates are opaque to the light from $Al_xGa_{1-x}As$ lasers, but transparent to the light from the new $In_xGa_{1-x}As$ lasers. Consequently, the new lasers can be made to emit either from their top surfaces or through the bottom surfaces of their substrates, without need to etch away parts of the substrates to obtain bottom-surface emission.

In fabricating the devices illustrated in the figure, the GRINSCH and SQW layers were grown by molecular-beam epitaxy. The $In_{0.15}Ga_{0.85}As$ active SQW layer was 60 Å thick. The GaAs layers above and below this layer, each 25 Å thick, served as growth-stopping layers. The two GRINSCH layers, each 1,400 Å thick, were made by linearly or parabolically grading the mole fraction, x, of AlAs (in $Al_xGa_{1-x}As$) from 0.05 to 0.5. The upper and lower cladding layers were 1.0-μm-thick $Al_{0.5}Ga_{0.5}As$, p-doped and n-doped, respectively. A cap layer of p^+ GaAs 0.2 μm thick was grown on top to facilitate ohmic contact. The entire structure was grown on a (100) n^+

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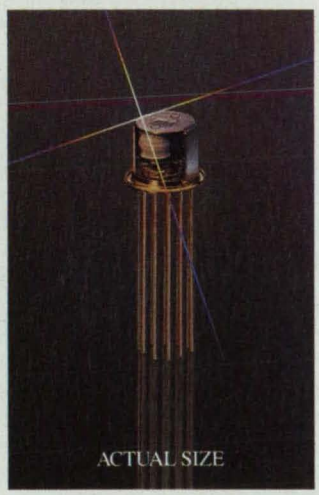

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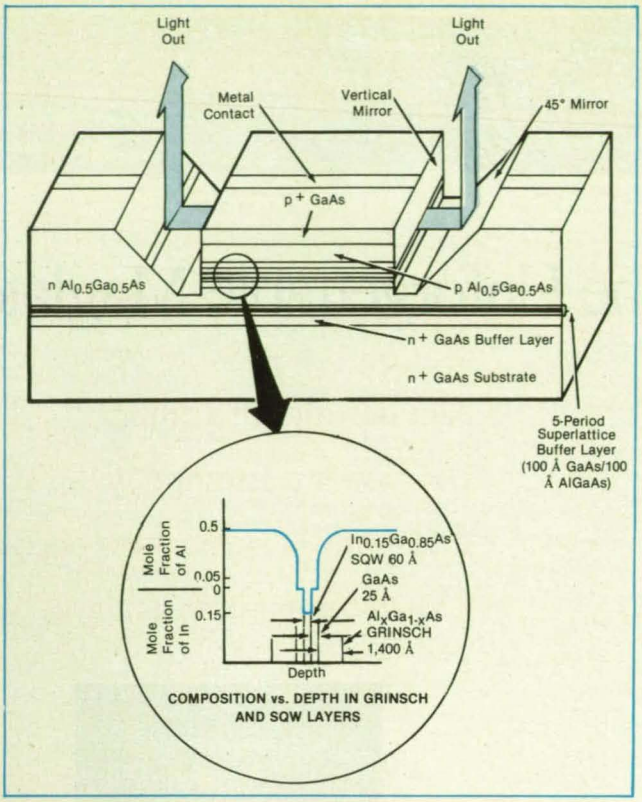

This Surface-Emitting Solid-State Laser emits light at a wavelength of 945 nm. Because the substrate is transparent to this light, the 45° mirrors could just as well have been oriented to deflect light out through the bottom.

GaAs substrate with both a 0.5-µm-thick n^+GaAs buffer layer and a 5-period superlattice buffer layer of 100 Å GaAs/100 Å $Al_{0.5}Ga_{0.5}As$.

The wafer thus fabricated was divided into laser stripes, each 100 µm wide. Vertical and 45° mirror surfaces were made by 30°-tilted ion-beam etching, defining laser cavities 200 to 550 µm long. Metal contacts were applied, and the stripes were scribed into separate lasers. In tests, these lasers exhibited low threshold currents (280 to 320 mA for 500-µm-long cavities), high peak powers (126 to 250 mW), and differential quantum efficiencies of 0.10 to 0.18 W/A.

This work was done by Jae H. Kim of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 159 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 20]. Refer to NPO-18243.

Broadband Active Antenna

The effective area of a search coil is increased.

Goddard Space Flight Center, Greenbelt, Maryland

The circuit shown in the figure can be regarded as an active antenna or, more specifically, an active search coil (magnetic-pickup coil). The circuit can also be regarded as a descendant of the regenerative detector, which was popular with radio experimenters during the 1920's. The circuitry connected to the search coil enhances the current induced in the search coil by an alternating magneting field, thereby making the effective area (for the purpose of reception of signals) of the coil greater than its geometric area.

Conventional straightforward linear small-signal analysis shows that the combination of operational amplifier A, resistors R_1, R_2, and R_3, and capacitor C acts as though it were a negative inductive reactance in series with a negative resistance. By suitable choices of the R_1, R_2, R_3, and C, this negative inductive reactance and negative resistance can be made slightly smaller than the positive inductive reactance and the positive resistance of the search coil, respectively. Therefore, the overall equivalent circuit has a net series inductive reactance and a net series resistance much smaller than those of the pickup coil. As a result, the voltage induced in the coil by the magnetic field gives rise to a much larger current than it otherwise would.

In effect, the circuit acts as though it is nearly resonant over a broad range of frequencies. To the degree to which the search coil behaves other than as pure

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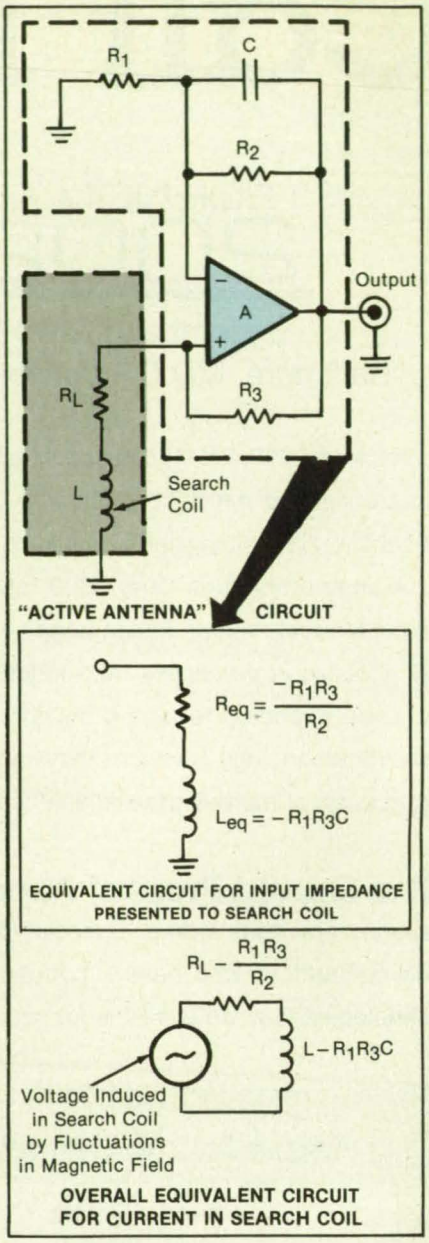
constant inductance in series with a pure constant resistance, the circuit departs from the desired broadband, nearly resonant response. In practice, to prevent instability and oscillation, it is necessary to choose the resistors and capacitor to provide sufficient reactance and resistance margins that at all operating frequencies and in the presence of noise, the net resistance and reactance will always be positive.

In its original application, the circuit is intended to enhance and broaden the frequency response of a search coil that is to be used in the spectral analysis of weak magnetic fields from about 3 Hz to about 3 kHz. A typical search coil for this application would consist of several thousand turns of copper wire on a ferrite rod; it would have $L \approx 2\ H$ and $R_L \approx 50\ \Omega$. Typical resistances and capacitance for this application would be $R_1 \approx 100\ \Omega$, $R_2 \approx 2\ M\Omega$, $R_3 \approx 1\ M\Omega$, and $C \approx 0.02\ \mu F$. The operational amplifier could be a Precision Monolithics OP-77 (or equivalent) or could be replaced by another transistor or vacuum-tube amplifier.

The Input Impedance presented to the search coil by the operational amplifier and its associated components nearly balances out the impedance of the search coil. As a result, fluctuations in the ambient magnetic field induce large currents in the search coil.



This work was done by John F. Sutton of **Goddard Space Flight Center**. *For further information, Circle 154 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 20]. Refer to GSC-13309.

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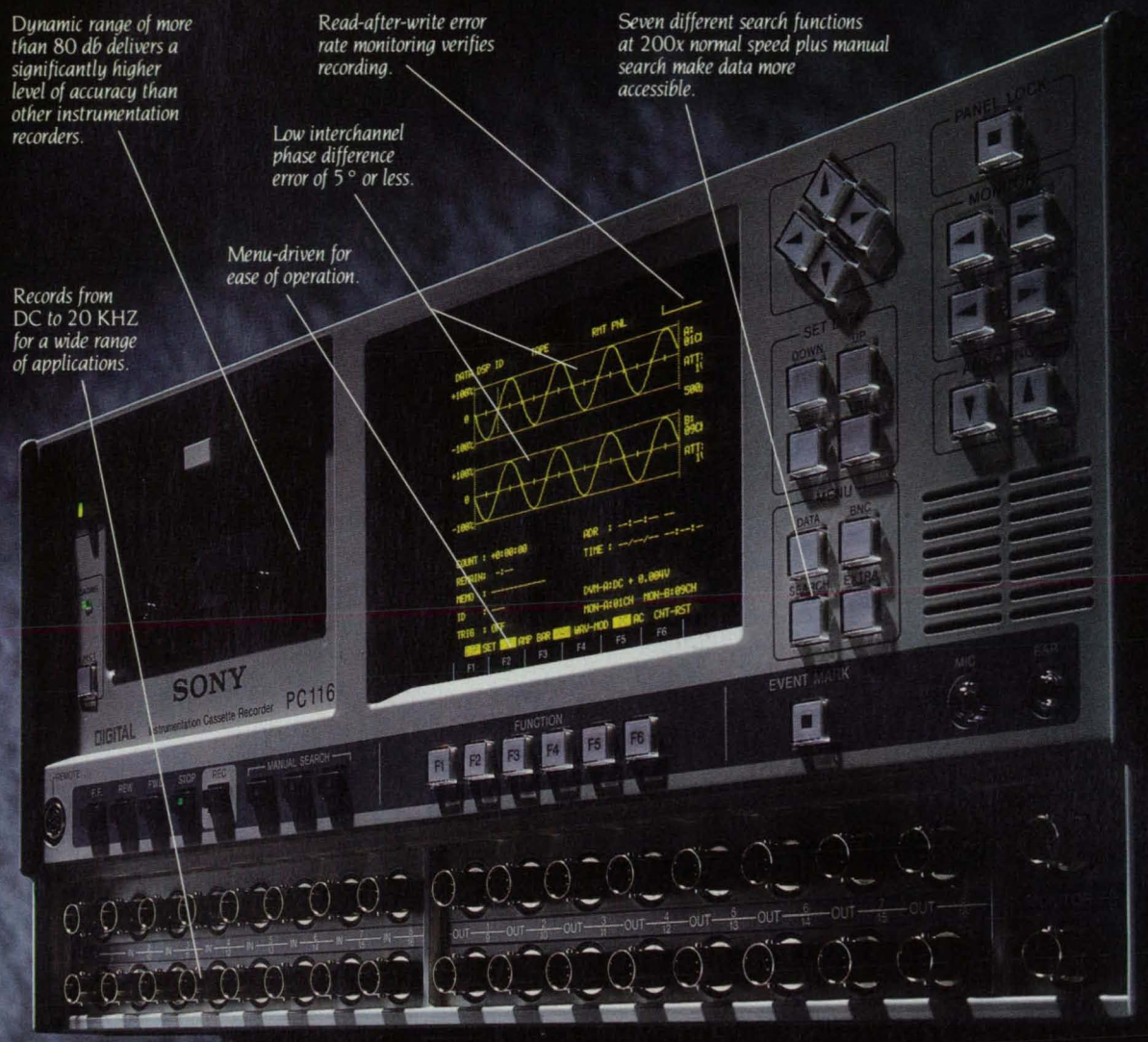

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Electrically Isolating Transmission-Line Driver

The transmission line would be isolated from common-mode input and ground.

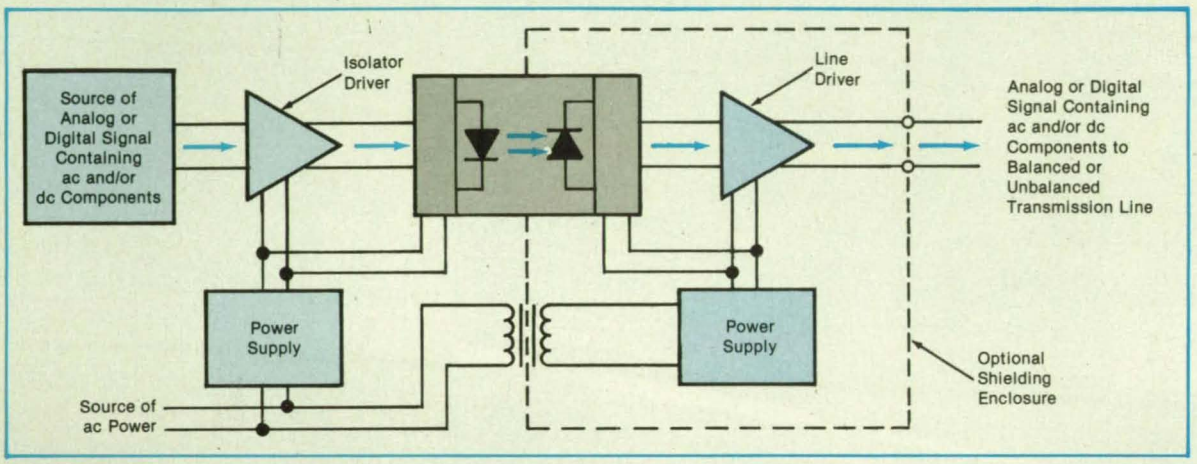
John F. Kennedy Space Center, Florida

A proposed optoelectronic coupling circuit would be used to insert a signal in a transmission line and to isolate the transmission line from the ground of the circuit in which the signal originates. The circuit, which could be made from commercially available components, would reduce the susceptibility to interference along the transmission path.

The heart of the circuit would be an optically coupled isolator (optocoupler) fed by a transformer-isolated power supply. An isolator driver on the input side would be fed by a separate power supply connected to the input-side ground (see figure).

The output of the optocoupler would be sent to a line driver also fed by the transformer-isolated power supply. An optional electrostatic shielding enclosure connected to an electrostatic shield between the windings of the power-supply transformer would contribute to the overall electrical isolation and rejection of common-mode and other interfering signals.

This work was done by Robert H. Marchman of Lockheed Space Operations Co. for **Kennedy Space Center**. *No further documentation is available.*
KSC-11393



An **Optocoupler and a Transformer-Isolated Power Supply** would assure the isolation of the transmission line from the ground of the signal source.

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Axial-Gap Induction Motor for Levitated Specimens

The motor does not obscure the view of the specimen.

NASA's Jet Propulsion Laboratory, Pasadena, California

An axial-gap induction motor applies torque to rotate an electrostatically or electromagnetically levitated specimen of metal. Like prior induction radial-gap induction motors, it applies torque by generating a rotating magnetic field that, in turn, generates and interacts with eddy currents in the specimen. However, unlike a radial-gap induction motor (which has a generally cylindrical shape and obstructs access to the specimen from most directions), the axial-gap induction motor imposes little, if any, additional restriction upon access to the specimen, beyond that already imposed by the levitating apparatus.

The axial-gap induction motor can be placed, for example, under the bottom one of two levitating electrodes (see Figure 1). Possible applications include turning specimens for uniform heating under focused laser beams and obtaining indirect measurements of resistivities or of surface tensions in molten specimens. The most important advantage of the axial-gap induction motor in these applications is that the paths of laser beams and the lines of sight of optoelectronic diagnostic equipment remain unobstructed.

Figure 2 illustrates the principle of operation. The motor includes four poles, each wound with a separate coil, arranged symmetrically around a disk. Coils L_1 and L_3 are connected in series with magnetic fields aiding and excited by a sinusoidally alternating voltage. Coils L_2 and L_3 are connected and excited similarly by a voltage of the same magnitude and frequency but at a phase that leads or lags the L_1/L_2 voltage by $\pm 90°$. The resulting magnetic field rotates at the frequency of the applied voltage. The direction of rotation can be reversed by reversing the 90° phase difference.

The motor was tested with an electrostatically levitated aluminum sphere that weighed about 0.3 g and had an outside diameter of 0.375 in. (9.5 mm). At an input power of about 10 W and a driving frequency of 200 Hz, the sphere rotated at about 600 rpm (10 Hz) in air. When the levitation chamber was evacuated, the sphere rotated somewhat faster than 5,000 rpm (about 83 Hz).

This work was done by Govind Sridharan, Won-Kyu Rhim, Dan Barber, and Sang Chung of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 55 on the TSP Request Card.*

NPO-18310

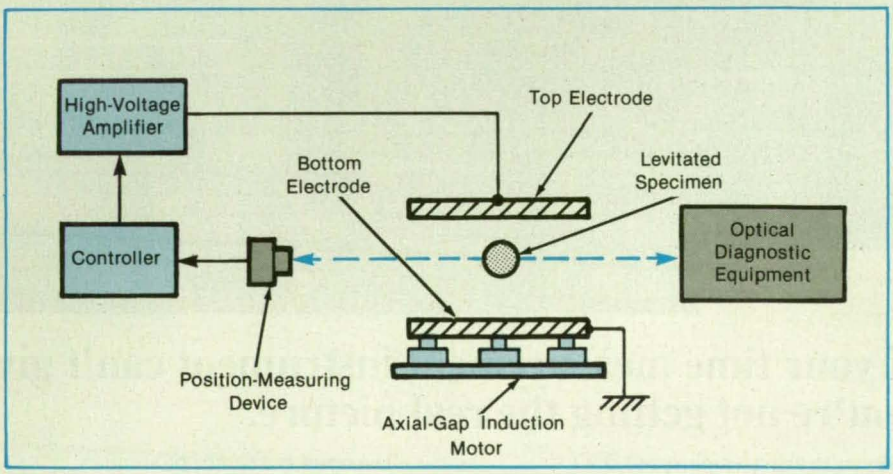

Figure 1. This Electrostatic-Levitation Apparatus can incorporate an axial-gap induction motor. The motor can be placed conveniently under the bottom electrode so that it does not block access to the levitated specimen.

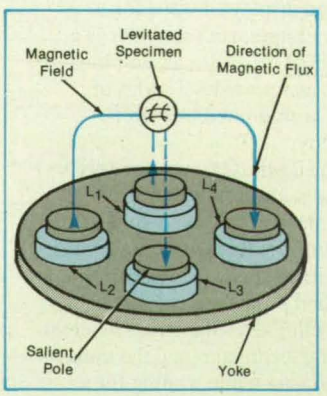

Figure 2. This Axial-Gap Induction Motor is a two-phase device that produces a rotating magnetic field. One could also construct such a motor with a greater number of phases.

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Electronic Systems

Integrated Scene and Graphics for Multiple-Camera Viewing

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NASA's Jet Propulsion Laboratory, Pasadena, California

A multiple-video-camera viewing system for monitoring a telerobot is undergoing development. When fully developed, the system will present the user with a variety of information on a single video display:

- A picture of the robot from any of five movable cameras,
- A graphical depiction of the location and orientation of the camera producing the current picture in the middle of the video display,
- A graphical depiction of the locations and orientations of the other cameras, and
- Graphical images of the fields of view of the cameras and their three-dimensional relationship to the workspace of the telerobot.

The display will help the user control the telerobot quickly and efficiently. The added information will normally be presented in a peripheral band surrounding the picture of the robot (see Figure 1). It is expected that the user will be able to observe the band by peripheral vision, without diverting attention from the picture itself; there should be no need for the user to waste time and become fatigued by repeatedly shifting the eyes back and forth between the picture and the outer information band.

The graphical images will ordinarily not overlie the picture of the robot and, therefore, will not ordinarily obscure it. When more space is needed for the peripheral information band, this band automatically expands while the picture of the robot in the middle shrinks and/or shifts. If it should become necessary to overlay graphical images on the picture of the robot, they could be presented semitransparently so that all the picture is still visible.

The user's workstation will include a large, high-resolution monitor, a graphics generator, and frame buffers. The user will select (perhaps by voice commands via a speech-recognition subsystem) which camera view will be displayed on the monitor. Each camera, mounted on a gantry around the workspace of the robot, will be moved in the plane of the gantry, tilted, and panned.

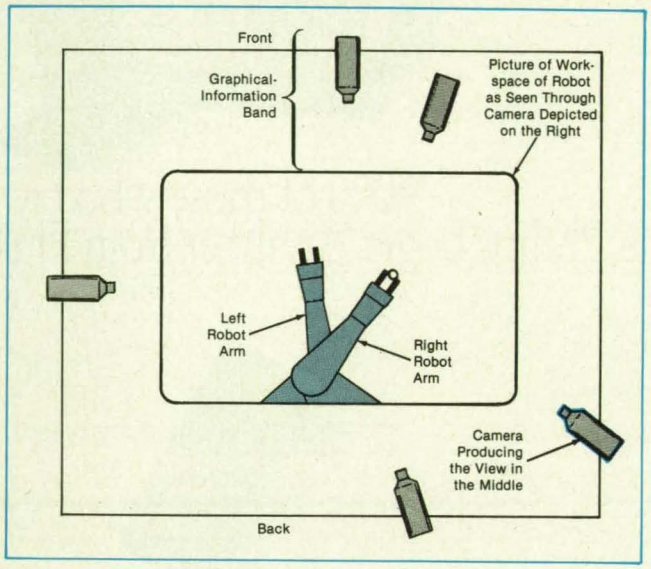

Figure 1. A **Graphical-Information Band Will Surround** the television picture of a robot on a high-resolution monitor. Camera icons in the band show positions and orientations of cameras.

On the monitor, the camera producing the picture in the middle will be highlighted in the information band, as in Figure 1. Depending on whether from the top or the side, the angular orientations of the camera icons will indicate the pan or tilt angles, and such labels as circles and bars will indicate the tilt or pan angles of the cameras, respectively. Numbers, colors, symbols, and the like next to each camera icon could be used to indicate camera height or depth. The user will, therefore, be aware of positions and orientations of the cameras and will be able to save time by repositioning and reorienting the cameras before switching the view from one to the other.

The user will be able to obtain a quick impression of the overall workspace of the robot by calling for a "wall-and-ceiling" display. A perspective grid that gives a three-dimensional appearance will be superimposed on the picture, showing the cameras and lights and a spotlight projection of the field of view of each camera, one by one in repeating sequence (see Figure 2).

This work was done by Daniel B. Diner and Steven C. Venema of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 91 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 20]. Refer to NPO-17836.

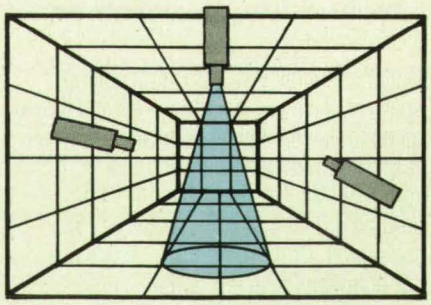

Figure 2. The **Wall-and-Ceiling Display** will give a perspective view of the workspace of the robot and the cameras. The spotlight projection of the field of view of the camera at the top will be followed in sequence by similar projections for the other cameras.

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Circle Reader Action No. 314

Electronic Control of Slow Rotations

A control circuit imitates a conventional (mechanically driven) synchro.

Marshall Space Flight Center, Alabama

A digital/analog circuit (see figure) controls both the angular position and the speed of rotation of a motor shaft with high precision. The circuit was designed in response to a need to lock the angular positions of two instrument shafts 180° apart while the shafts rotate at the precisely commanded rotational frequency of 0.25 Hz. The circuit or a modified version of it could be used to control precisely the position and velocity of a robotic manipulator, to control the translation mechanism of a crystal-growing furnace, to position the hands of a mechanical clock, or to control the angular position and rate of rotation in any of a large variety of rotating mechanisms.

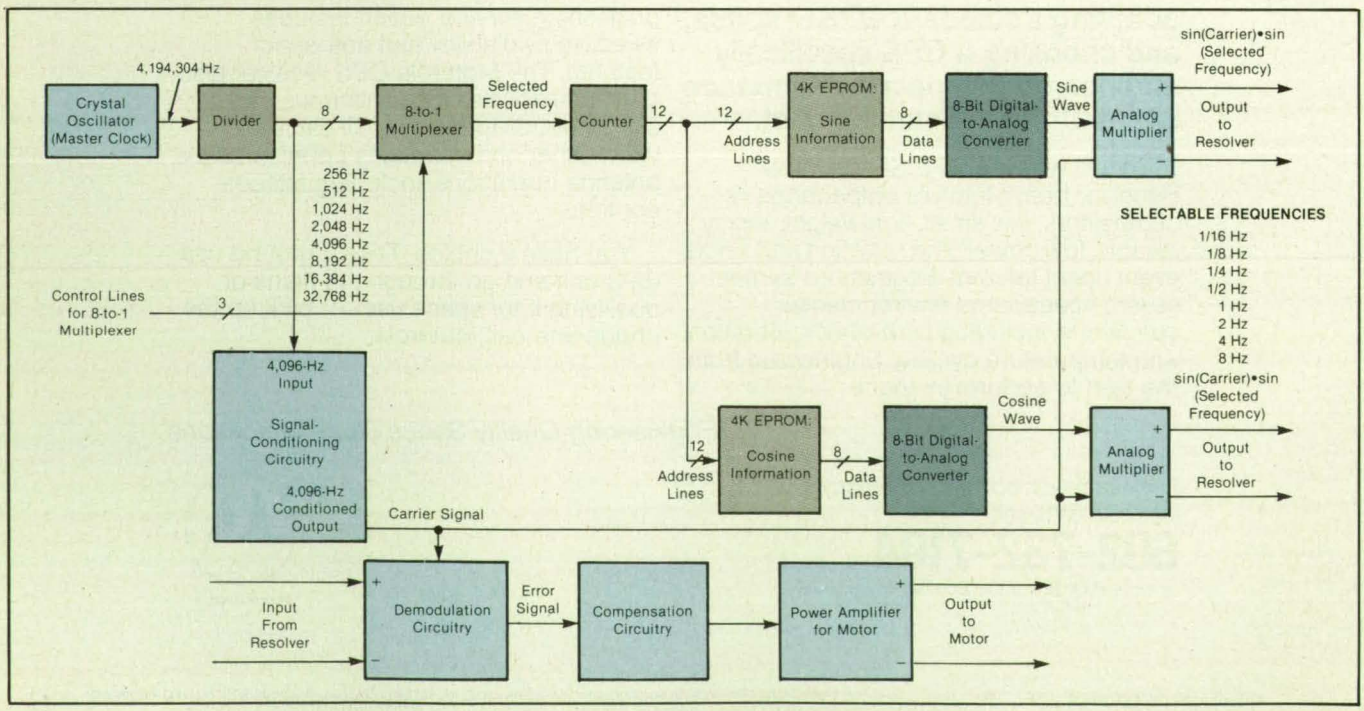
The overall function of the circuit is to lock the angular position of the motor to the phase of a rotation-command clock signal at a binary submultiple of a master clock signal. A crystal oscillator provides the master clock signal, which has a frequency of 4,194,304 Hz. This clock signal is fed to a frequency-dividing and -multiplying circuit that puts out eight selectable signals at binary submultiple frequencies from 256 to 32,768 Hz. One of these — the 4,096-Hz signal — is conditioned to provide a stable 4,096-Hz square, sinusoidal, triangular, or other waveform, from −10 to +10 V, that serves as a carrier signal.

The eight selectable signals are used to control the rate of rotation of the motor. The selected signal is fed into a 12-bit counter, the output of which is used to address two electrically programmable read-only memories (EPROM's). Both EPROM's act as "lookup tables"; one contains digitized sine information, while the other contains digitized cosine information. As the counter increments, the sine and cosine information is passed to digital-to-analog converters, which put out sine and cosine waves at a frequency that corresponds to the desired rate of rotation.

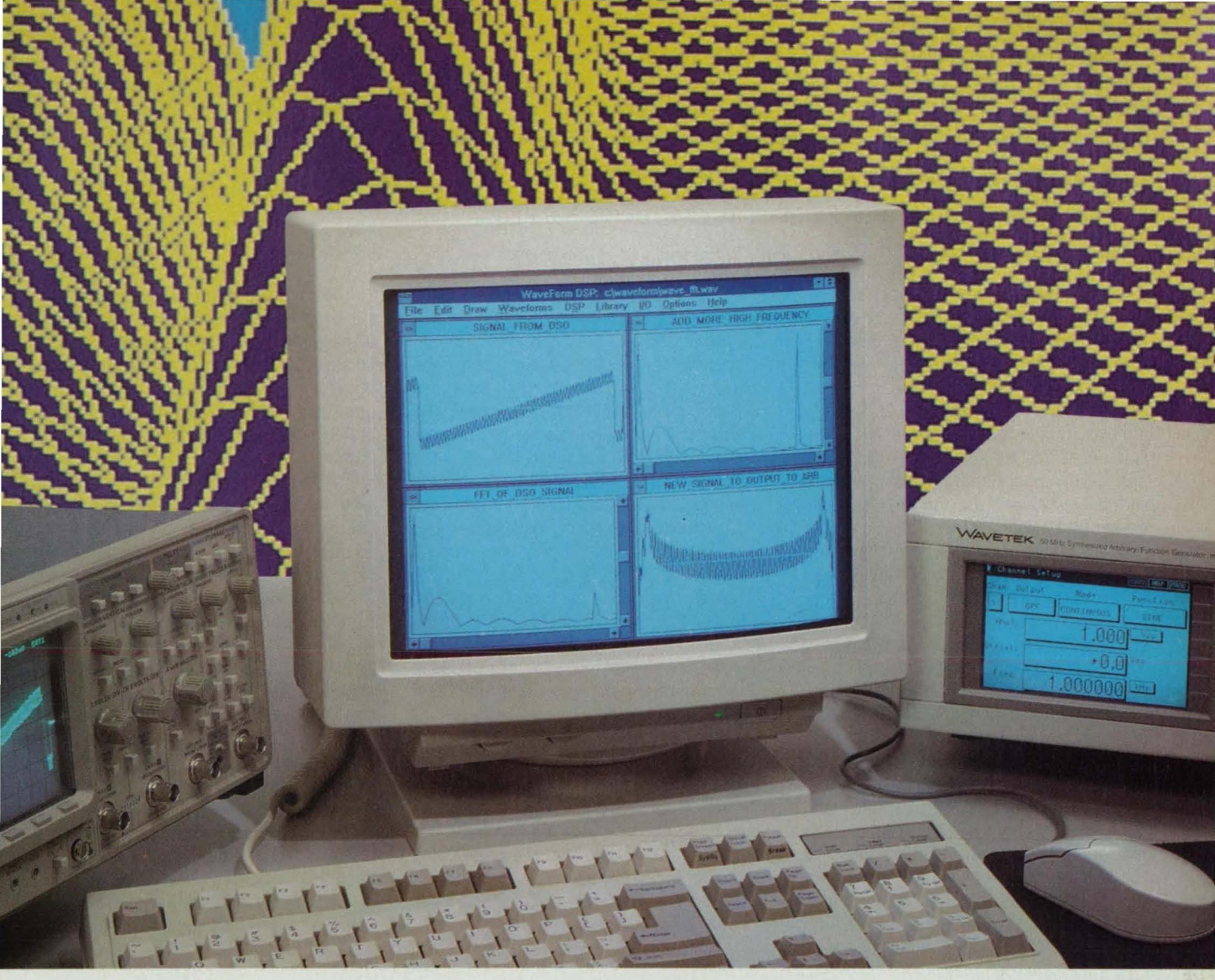
The sine and cosine waves are multiplied by the carrier signal. The product signals are used to excite a resolver: these are the same as the signals that would be provided by a mechanically driven synchro (selsyn generator) in a standard synchro/resolver/follower combination. The output of the resolver is demodulated from the carrier frequency to provide the error signal that indicates the difference between the commanded and actual rates of rotation and that is used to control the motor.

The basic circuit can be modified in several ways. The frequency of the crystal oscillator can be changed, or the crystal oscillator can be replaced with a voltage-controlled oscillator to obtain a more dynamic range of commanded rotational rates. The motor can easily be commanded to a fixed position by stopping the clock when the EPROM address counter holds the count that corresponds to the desired angular position. An EPROM of greater capacity can be used to increase the definition of the digitized sine and cosine information, thereby obtaining better angular accuracy. Greater accuracy can also be obtained by use of digital-to-analog converters of higher resolution. (The number of output data lines from the EPROM's must equal the number of input data lines to the digital-to-analog converters.) The direction of rotation can be commanded by replacing the 12-bit counter with a 12-bit up/down counter and toggling the up/down control line.

Other than the equipment already mentioned, no additional motor, synchro, or related electrical and mechanical equipment normally used in synchro/resolver/follower systems is required. The circuit is not vulnerable to the drifts associated with many analog components and does not require any "fine tuning" or adjustments, as an equivalent analog design would. The circuit can be made to control accurately the rate of rotation of a shaft down to 1 revolution per day or less by increasing the size of the EPROM and the resolution of the digital-to-analog converters. This eliminates the need for expensive and massive tachometers, which are normally used to measure very low speeds of rotation. This also eliminates such other disadvantages of tachometers as brush wear.



The **Shaft-Position and -Speed Controller** generates signals for the precise control of slow rotations of a motor equipped with a resolver (a device that puts out sine and cosine signals indicative of the angular position).



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This work was done by David E. Howard and Dennis A. Smith of **Marshall Space Flight Center**. *For further information, Circle 93 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28458.

Control System for Spacecraft Ballistic Trajectory

Nonlinear parameters are identified for drag compensation.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed system would sense nongravitational accelerations and control the trajectory of a spacecraft in a close encounter with the Sun or the massive outer planets in order to perform relativistic and gravitational science experiments. The system would compensate for drag from the solar-wind and for solar-radiation forces, and for any other nongravitational effects, with a view toward making the trajectory as nearly ballistic as possible.

The inertial sensing element of the control system would be a proof mass floating in the nominally gravitationless environment of a sensing chamber fixed to the spacecraft. The overall control strategy would be to fire the spacecraft thrustors and/or activate reaction wheels as needed, gently maneuvering the spacecraft and chamber around the proof mass so as to keep the chamber centered on (and not touching) the proof mass.

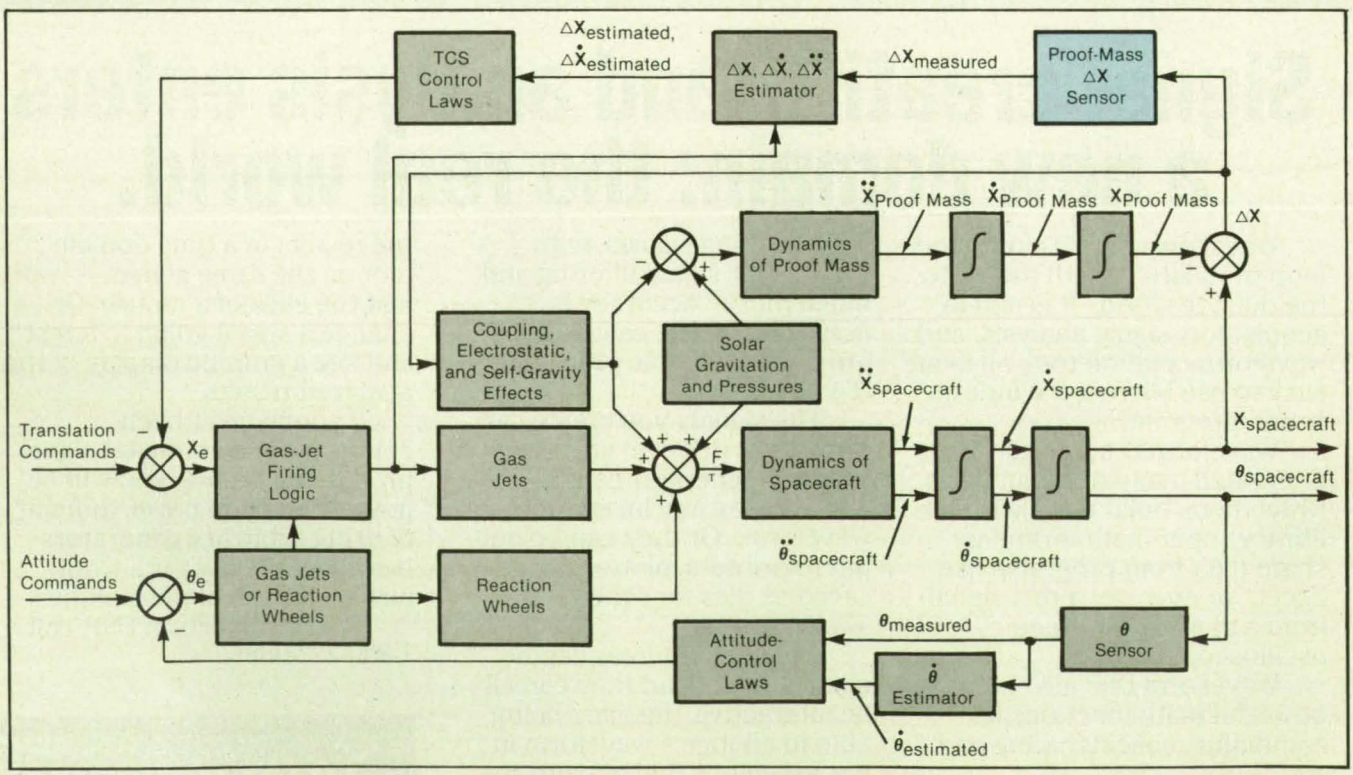
An earlier earth-orbiting experimental spacecraft, named TRIAD, was gravity-gradient-stabilized and uniquely configured to have the drag sensing element at the center of mass and all other vehicle mass remoted from the sensor by three long symmetrical booms. This provided a nearly ideal benign disturbance and self-gravity environment.

In the present deep-space mission to the Sun and/or outer planets, the proof mass will not, by practical necessity, be at the center of mass of the spacecraft. This will result in dynamic coupling between the attitude- and translation-control loops and must be carefully considered in the control system design. Also the nonideal mass symmetry of the spacecraft with respect to the proof mass, the movement of the antenna, the articulation of scientific instruments, the depletion of fuel, and thermal distortions of the spacecraft will introduce "self-gravity" disturbances because the proof mass will respond to them as it would to gravitational perturbations.

The proof mass could also acquire a net electrostatic charge from energetic particles in outer space, and so the control system would have to account for any net electrostatic force between the chamber and the proof mass. This is a particularly important issue when the spacecraft is in the vicinity of the Sun or the radiation fields of the outer planets.

The solutions to the unique issues faced in the development of a control system for a drag-free spacecraft are generic to a class of problems that require integration of dynamic state estimation, plant-parameter and nonlinear-disturbance identification, and nonlinear-limit-cycle-control authority.

The dynamics of both the plant and its inertial-position-reference sensor are nonlinearly coupled through the inverse-square-law destabilizing forces generated by local gravitational fields, electrostatic and electromagnetic fields, and energetic particle radiation fields. It will be necessary to dither the sensor precisely to identify the disturbing forces without destabilizing the controller. Nonlinear estimation methods would be employed to analyze the sensor dynamics and determine these forces. The plant controller would then operate on a compensated sensor-error signal to perform a reference-tracking function. Since the translation control authority is impulsive, an integral-error control action is used to adjust the switching lines of the limit cycle to bring the error to the desired value. Terrestrial applications of



The **Control System** would maintain position with respect to a proof mass that moves in an environment as free of forces as possible.

these estimation, identification, and control methods could range from inertial guidance of submarines, ships, and aircraft to advanced process control of materials and measurement of extremely small forces.

The control system (see figure) would be effective in three translational and three rotational degrees of freedom. The translation control would be referenced to the position, $\Delta\mathbf{X}$, of the proof mass relative to the spacecraft, while the spacecraft position would be referenced to inertial coordinates derived from radiometric telemetry data. $\Delta\mathbf{X}$ would be measured by a capacitance bridge or an optical sensor. $\Delta\mathbf{X}$ as measured would be combined with information about current activity of the control system (i.e., number and direction of thrustors that are firing) and with a mathematical model of the dynamics of the spacecraft to generate estimates of $\Delta\mathbf{X}$, $\Delta\dot{\mathbf{X}}$, and $\Delta\ddot{\mathbf{X}}$.

The estimates of $\Delta\mathbf{X}$ and $\Delta\dot{\mathbf{X}}$ would be used in the translation-control equations to calculate the translation error, $\mathbf{X}_e$. Next, the summed translation error would be evaluated by the firing logic to determine whether control action (i.e., firing thrustors) should be taken. The firing logic could also evaluate attitude error simultaneously, so that a combined but somewhat degraded attitude and translation control could be effected by thrustors alone. Although thrustors or reaction wheels could be selected, reaction wheels would be the primary attitude control effectors since they greatly minimize dynamic coupling between the rotational- and translational-control loops.

The inertially referenced attitude-control loop would effect a proportional position-plus-rate-control law and would operate independently of the translation controller to maintain attitude stability. The attitude of the spacecraft would be sensed by Sun sensors and star trackers during cruise, and by gyroscopes during close encounters with the Sun or massive planets.

This work was done by Edward Mettler, Mark H. Milman, Richard W. Key, and David B. Schaechter of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 27 on the TSP Request Card.*
NPO-16037

Initializing Embedded Data Processors From a Single Source

Remote processors are given an image of a startup diskette so that a real local diskette and drive are unneeded.

Lyndon B. Johnson Space Center, Houston, Texas

An initial-computer-program-loading system provides startup information to all embedded data processors (EDP's) in a general-purpose computer system. Initial program loading makes it unnecessary to include a floppy-disk attachment in each remote EDP to furnish startup information; instead, remote EDP's can be "booted up" from a single EDP over the data bus of the computer system. The system is therefore less complex, and the equipment costs less.

An additional benefit is that initial program loading tests the bus. If the boot-up program is transmitted correctly, the bus is assumed to be operating properly.

One of the EDP's in the general-purpose computer receives its boot-up information from a local mass-storage device. Once it is initialized, it sends the boot-up information to the other EDP's in the system.

When power to the general-purpose computer goes on, the EDP's are energized simultaneously. They go through their power-on self-tests. The EDP that is equipped with mass storage brings up its operating system from its disk. It starts a remote-initial-program-loading server program, which broadcasts a message to inform remote EDP's that it is available. The remote EDP's send diskette-read requests to the server, which sends the requested information to them. When their operating systems are fully loaded, their diskette-image files appear to the remote EDP's as if they were real diskettes in real drives.

If, for any reason, a remote EDP is rebooted, it reissues its request for startup information. The remote initial loading program retransmits the information.

This work was done by Edward A. Chavez, John J. D'Ambrose, Richard D. Petras, and Michael R. Turner of International Business Machines Corp. for **Johnson Space Center**. *For further information, Circle 40 on the TSP Request Card.*
MSC-21647

Predicting Clear-Air Turbulence From Microwave Radiometry

Aircraft could predict and avoid turbulence.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed microwave radiometer system aboard an aircraft would scan the sky and predict the likelihood of turbulence and indicate how to avoid it. It is desirable to avoid encounters with clear air turbulence (CAT) because it occasionally injures passengers, is a distraction to the pilots, increases fuel consumption, and causes airframe-metal fatigue.

The proposed system would combine the microwave-instrument measurement of vertical temperature gradient with an inertial navigation-system measurement of wind vector and provide warnings about the time and severity of an upcoming CAT, and indicate how to avoid it. The system would also save fuel by making it unnecessary to detour around regions that conservative forecasts indicate might contain CAT, through which, instead, one can be navigated more efficiently by following altitude-avoidance advisories of the proposed instrument.

The proposed system would include a scanning microwave radiometer similar to one that has been used in airborne studies of the Antarctic ozone hole. The passive microwave radiometer measures thermal emission from oxygen molecules at one or more frequencies near 57 GHz. The instrument would scan through an elevation range of −60° to +60° every few seconds, and convert measured intensities to air temperature versus altitude. The temperature profile would extend across an altitude region approximately 5-km thick, centered on the aircraft's altitude.

These air temperatures would be converted to potential temperature, θ, versus altitude, z. θ is the temperature an air parcel would have if it were adiabatically compressed to a standard pressure of 1 bar (0.1 MPa). The foregoing information would then be used to compute the vertical gradient of θ, $d\theta/dz$.

The next step would be to determine vertical wind shear, dW/dz, which is the orthogonal sum of the vertical gradient of U and V, the east–west (EW) and north–south (NS) components of the wind. This would be done by first calculating the dependence of U and V upon θ: $dU/d\theta$ and dV/d. This is made possible by the fact that an aircraft is always flying through a wrinkled pattern of isentropes (surfaces of equal potential temperature) and isotachs (surfaces of equal wind speed). An ever-present background of up and down air motions moves the isentropes and isotachs together, creating the wrinkled pattern. An aircraft flying through the wrinkled pattern will measure variations of θ, U, and V, allowing for the calculation of $dU/d\theta$, $dV/d\theta$, and hence $dW/d\theta$:

$$\frac{dW}{d\theta} = \sqrt{\left(\frac{dU}{d\theta}\right)^2 + \left(\frac{dV}{d\theta}\right)^2}$$

The proposed system would calculate this gradient and then multiply it by the vertical gradient of potential temperature to produce vertical wind shear:

$$\frac{dW}{dz} = \frac{dW}{d\theta} \times \frac{d\theta}{dz}$$

The next step would be to calculate Richardson number, Ri, which can be regarded as the ratio of stabilizing forces to overturning forces:

$$Ri = \frac{g}{\theta} \times \left[\frac{d\theta}{dz}\right] \Big/ \left[\frac{dW}{dz}\right]^2$$

where g is the gravitational constant. When $Ri > 1$, the atmosphere is stable and CAT is unlikely because small perturbations are suppressed. When $Ri < 1/4$, small perturbations can grow and produce CAT. Prior to encountering CAT there will be a downward trend of Ri from typical values, in the range 10 to 100, to values below 5 and approaching 1/4. This pattern of decreasing Ri would be used to issue warnings of imminent CAT.

CAT severity could be determined from the magnitude of stored wind energy per unit increment of altitude. This involves the evaluation of $(dV/dz)^2$ for the extrapolated condition $Ri = 1/4$.

Upon determining that CAT is imminent at the aircraft's flight level, the pilot can be advised to either climb or descend depending on which maneuver offers the quickest escape. The microwave temperature profiler will indicate the altitude region where CAT will be generated, since CAT-producing wind shear is almost always confined to such temperature structures as inversion layers and the tropopause.

This work was done by Bruce L. Gary of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 100 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 20]. Refer to NPO-18115.

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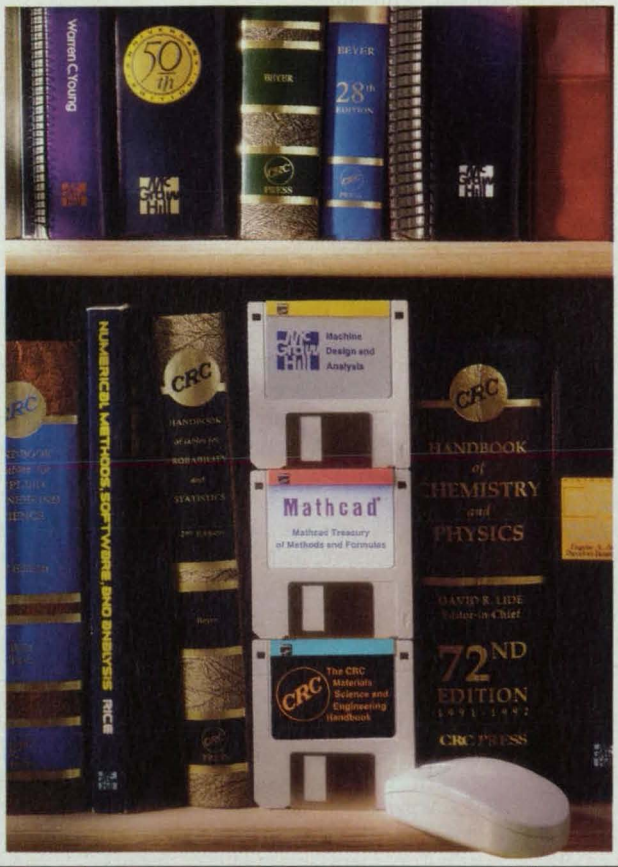

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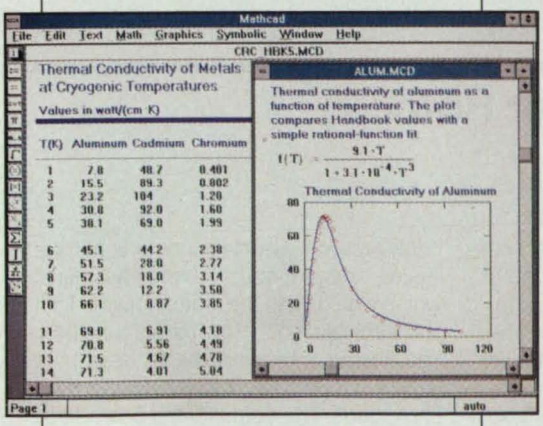

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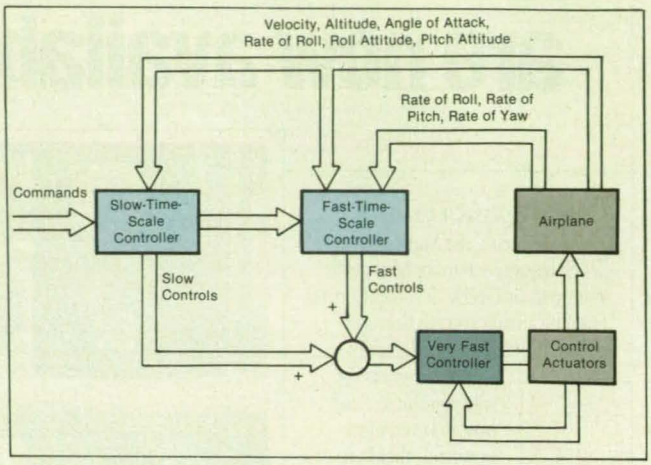
Nonlinear Maneuver Autopilot

Trajectory-control laws are based on singular-perturbation theory and nonlinear dynamical modeling.

Ames Research Center, Moffett Field, California

Progress has been made in the effort to develop a maneuver autopilot that would control test-flight trajectories of an F-15 airplane. Unlike many prior electronic control systems, this one would not be based on a mathematical model of the airplane in which the dynamics are represented by a linear approximation or series of such approximations. Instead, the mathematical model in the proposed autopilot would be constructed to express the nonlinear dynamics of the aircraft and controls taken together as a system, and recent developments in the theory of the control of nonlinear systems would be used in designing the autopilot.



The **Nonlinear Maneuver Autopilot** would command flight-test trajectories of an F-15 airplane. The underlying theory of this type of controller would enable the separation of variables to be processed in fast and slow control loops, reducing the amount of computation required.

A systematic approach to the development of control systems of the proposed kind is based on the theory of singular perturbations and the theory of prelinearizing transformations. The application of singular-perturbation theory simplifies the prelinearizing transformation considerably and provides consistent means for the elimination of ignorable state variables. Within this theoretical framework, the state variables in the original nonlinear problem are retained, while the control variables are transformed.

One of the advantages of this approach is that the representation of the dynamics can be split on the basis of the speeds of evolution of the state variables in such a way that the computations for some control loops can be performed at rates much lower than for others (see figure). In the fast-time-scale loops, the slow-time-scale variables are treated in the computations as though they were constants. A controller designed according to this approach could be implemented more efficiently than a more conventional controller can be because it would require fewer computations.

As part of continuing development, a controller of the proposed type was synthesized mathematically by using a nonlinear mathematical model of the airplane. The synthetic controller was expressed as a set of equations for the control of airspeed, altitude, angle of attack, and roll attitude. This controller was tested in a computer simulation with the help of a previously developed computer model of the airplane and of its command-augmentation system (the system of equipment through which the pilot, autopilot, and control surfaces of the airplane interact). The simulation included the following test trajectories: acceleration in level flight, pushover/pullup zoom and pushover, excess-thrust windup turn, constant-thrust windup turn, and constant-dynamic-pressure, constant-load-factor trajectory.

The results of the simulation indicate that (1) the command-augmentation system is stable and sufficiently fast and (2) the equations of the maneuver autopilot make this autopilot sufficiently robust in the face of inaccuracies in the mathematical model that the airplane can be controlled with high accuracy. Provided that the mathematical models of the dynamics of the airplane and of the command-augmentation system are accurate, one would expect the control system to respond satisfactorily during a flight test.

This work was done by P. K. A. Menon, M. E. Badgett, and R. A. Walker of Integrated Systems, Inc., for **Ames Research Center**. *Further information may be found in NASA TM-179442 [N90-11487], "Nonlinear Maneuver Autopilot for the F-15 Aircraft."*

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ARC-12560

Optical Detection of Ice on a Helicopter Rotor

Ice would alter the polarization of reflected light.

Goddard Space Flight Center, Greenbelt, Maryland

Ice forming on helicopter rotor blades under adverse weather conditions would be detected via its effect on the polarization of reflected light, according to a proposal. An ice-detection system based on this principle could alert the helicopter pilot to the need for corrective action, and/or it could turn on deicing equipment automatically. A timely response is essential because ice on the rotor blades reduces lift, possibly causing the helicopter to fall.

The figure illustrates one version of the proposed ice-detection system. An AlGaAs laser diode would generate predominantly linearly polarized light (polarization ratio $> 200:1$). The laser beam would be collimated by a lens and directed toward the leading edge of a rotor blade by a scanning mirror. The reason for scanning the leading edge is that studies have shown that ice forms there first. The motion of the scanning mirror would be synchronized with that of the rotor (typical rotation frequency ≈ 5 Hz) in such a way that the beam would strike perpendicularly to the leading edge and scan the entire leading edge of each blade from root to tip.

Some of the light reflected from the blade would travel back along the axis of the illuminating beam to three receivers. Each receiver would include a linear polarizer and an optical band-pass filter, which would pass the reflected laser light and eliminate most of the background light. The filtered light would be focused by a lens onto a positive/intrinsic/negative (PIN) photodiode. The output of the photodiode would be band-pass-filtered at the frequency of rotation with a 1-Hz bandwidth to reduce background-light signals further and to reduce signals caused by the scattering of laser light from airborne ice crystals and drops of water.

The linear polarizers of receivers 1, 2, and 3 would be oriented so that the re-

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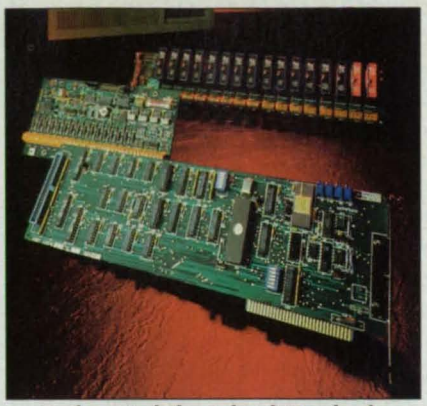

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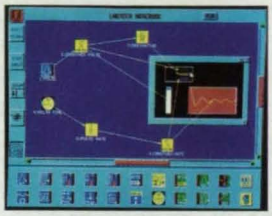

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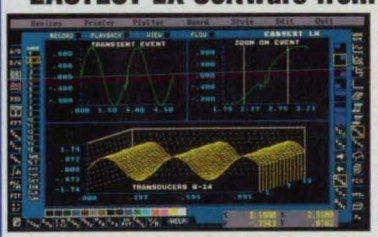

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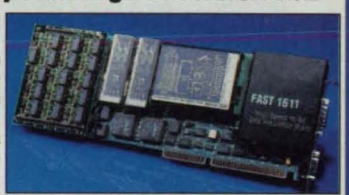

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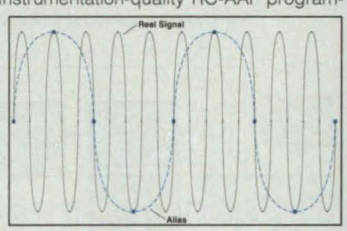

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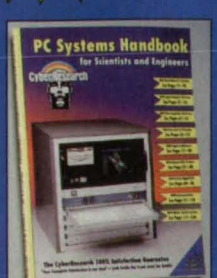

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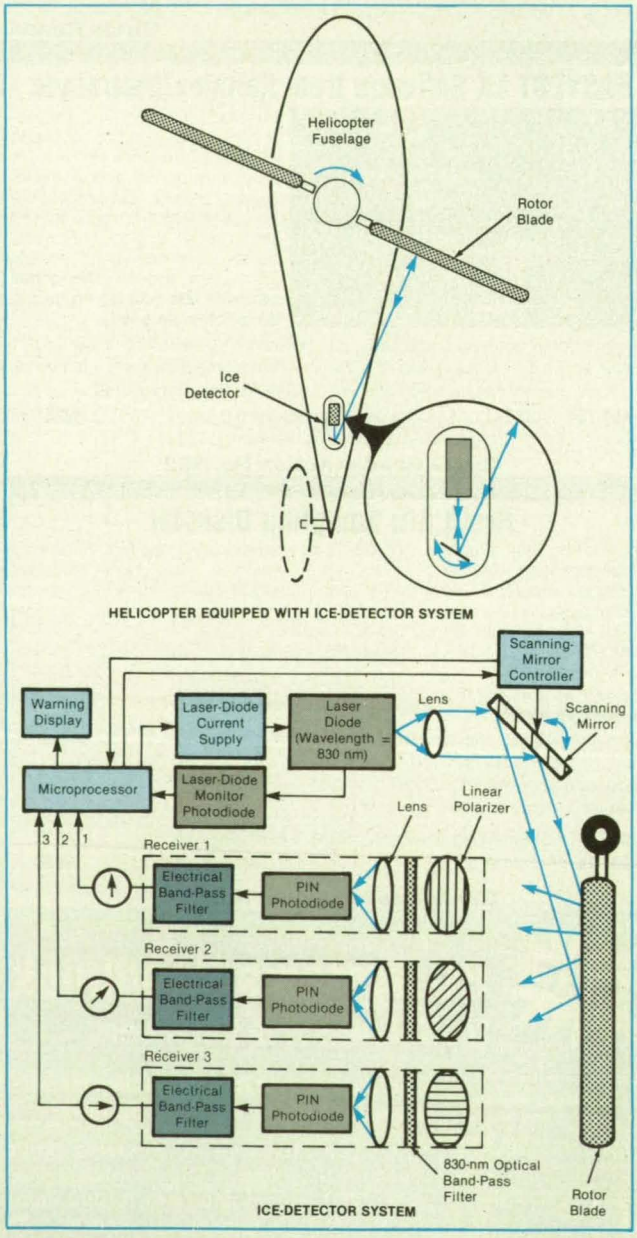
ceivers would be sensitive to light linearly polarized at 0°, 45°, and 90°, respectively (where 0° denotes the angle of linear polarization of the illuminating laser beam). The outputs of the receivers would be digitized and converted to relative amplitudes as functions of scan time. These digitized outputs would be compared in a microprocessor with the digitizied outputs obtained during a previous calibration scan that was taken when no ice was present. The deviations of the digitized quantities of the present scan from those of the "no-ice" scan would be quantified and compared with calibration criteria to determine whether the polarization of the reflected light differs significantly from the "no-ice" polalrization, indicating the presence of ice. If so, the microprocessor would activate an alarm.

This work was done by Donald M. Cornwell, Jr., and Paul L. Spadin of **Goddard Space Flight Center**. *For further information, Circle 37 on the TSP Request Card. GSC-13391*



Ice on the Leading Edge of the rotor blade would alter the polarization of reflected laser light. The system would respond to a significant change in polarization by issuing an alarm so that the pilot would respond to the incipient icing hazard.

Modification of a Communication Switch in a Helicopter

The pilot could pay more attention to flight control during critical maneuvers.

A report describes a preliminary study of a modification of electronic circuitry connected to communication-channel-selecting switches in the AH-1 Cobra helicopter. The switches in question are a foot switch and a cyclic thumb-wheel switch mounted on the joystick flight control. The modification was proposed by Army pilots to enable pilots and other crewmembers to select radio channels or intercommunication (that is, communication among crewmembers) with less diversion of attention from flight control and other critical tasks. The modification is intended to enhance safety and performance in critical situations; for example, in nap-of-the-Earth flight maneuvers during combat.

The cyclic switch on the joystick and the foot switch operate in conjunction with a noncyclic, six-position rotary switch on the control panel. In the unmodified configuration, only two of a total of four positions of the cyclic switch are used, and two operating modes are available. In one mode, the panel switch is placed in "ICS" (intercommunication system) position, the foot switch is used to key the ICS, and the cyclic switch is used to select intercommunication only. In the other mode, the panel switch is set to the desired radio channel, the foot switch is used to key radio communication on that channel, and the cyclic switch is used to select intercommunication or radio communication. The major disadvantage of the unmodified configuration is that to change radio channels, the pilot or other crewmember must divert attention from the critical control task at hand and look inside the cockpit to change the position of the rotary switch on the control panel.

In the preferred version of the modified configuration, all four positions of the cyclic switch would be used, and there would be two operating modes. In both modes, the cyclic switch could be used to select ICS or one of three radio channels. In one mode, the panel switch would be set in "ICS" position, and the foot switch would be used to key the ICS. In the other mode, the foot switch would be used to key the radio channel selected via the rotary panel switch.

The modified configuration was judged favorably by pilots in flight tests. Pilots found that they were able to keep both hands on flight controls while changing radio channels. They also reported increased awareness, increased capability to communicate, and increased safety. Some minor deficiencies were identified in the flight tests, but presumably can be corrected via a combination of flight tests, secondary modifications, and training to eliminate carryover of inappropriate operating habits from the unmodified configuration.

This work was done by Loran Haworth, Zoltan Szoboszlay, and Robert Shively of the U.S. Army Aviation Research and Technology Activity and Frank J. Bick of the U.S. Army Aviation Systems Command for **Ames Research Center**. *Further information may be found in NASA TM-101053 [N89-20978], "AH-1S Communication Switch Integration Program."*

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ARC-12661

Physical Sciences

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Smoke Generator for Studies of Vortices in Flight

Vortex cores and breakdowns can be located.

Ames Research Center, Moffett Field, California

A smoke-generating system has been used successfully to identify vortex-core and vortex-core-breakdown locations in flights of an F-18 airplane modified for research on flight at large angles of attack (see Figure 1). Smoke generators of this type may be useful for other aerodynamic flight research in which it is necessary to visualize local flows. Nonaerospace applications could include research in the reduction of aerodynamic drag on vehicles and the reduction of turbulence related to structures or other obstacles.

Housed in the forebody of the airplane, the smoke-generating system includes multiple pyrotechnic smoke cartridges that can be fired simultaneously or in sequence. The firing of the cartridges is controlled from the cockpit, and the smoke produced is ducted to desired locations on or near the surface of the aircraft.

Each cartridge is a steel canister 2.4 in. (6.1 cm) in diameter and 4.7 in. (11.9 cm) long, contains a specially developed pyrotechnic chemical mixture, and is equipped with an electric ignitor unit. It produces nontoxic smoke at a high rate and is designed to minimize fire hazards and accidental detonation during handling. Each cartridge is contained in one of six individual cylinders, 4 in. (10.2 cm) in diameter, in a housing, as shown in Figure 2. There are two housings: one on each side of the airplane.

The cylinders are equipped with coupler latches for rapid loading and unloading of cartridges and with sensors to monitor their temperatures. An independent temperature-controlled 5-A heater blanket surrounds each cylinder to maintain its temperature between 50 °F (10 °C) and 130 °F (54 °C) at flight altitudes before ignition. Ignitor wires are fed through a fitting on each cartridge cylinder and are connected to a squib terminal strip on the aft end of each housing. The squib terminal strip is terminated at a single connector, which includes a shorting device to protect against inadvertent ignition of the cartridges.

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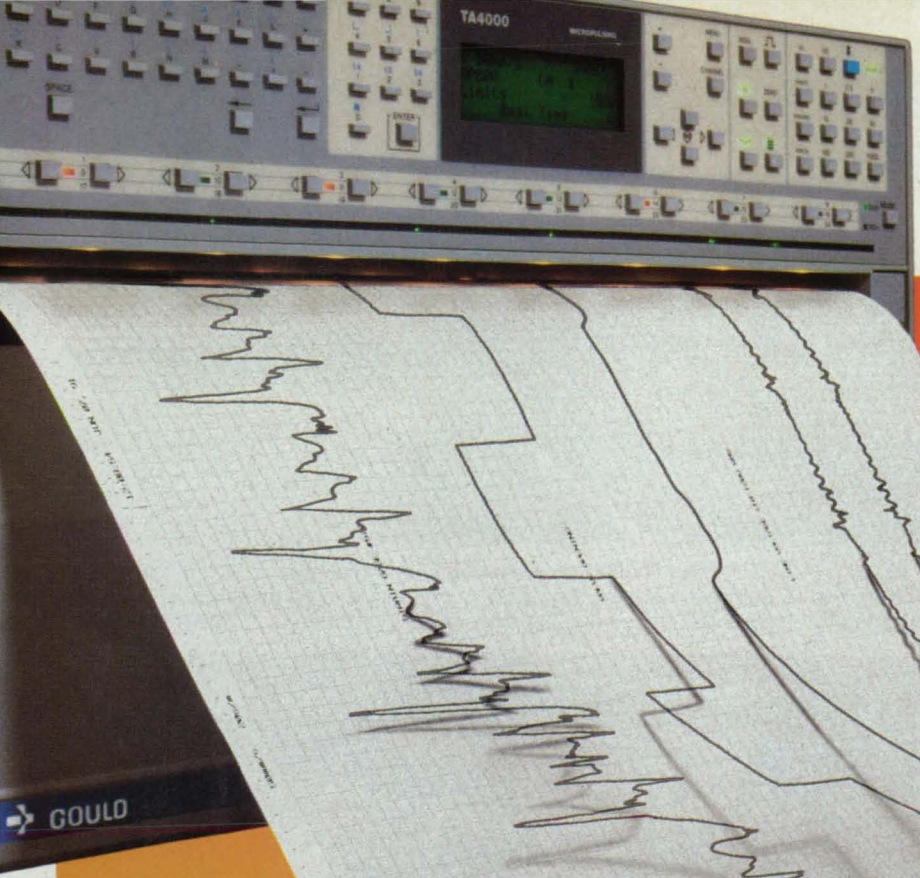

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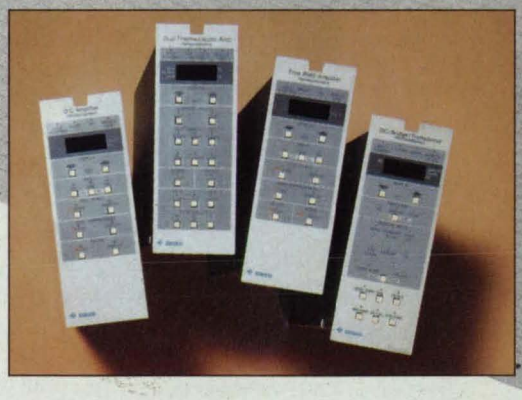

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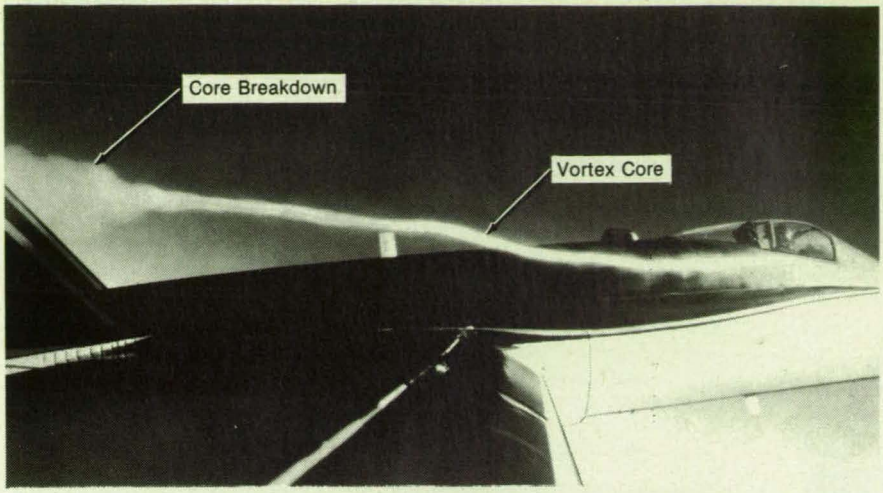

Figure 1. A **Smoke-Flow-Visualization Photograph** taken from a 35-mm camera on the tip of the right wing shows the vortex core and the core breakdown. The angle of attack is 19.6°, the airspeed is mach 0.31, and the altitude is 23,000 ft (7 km).

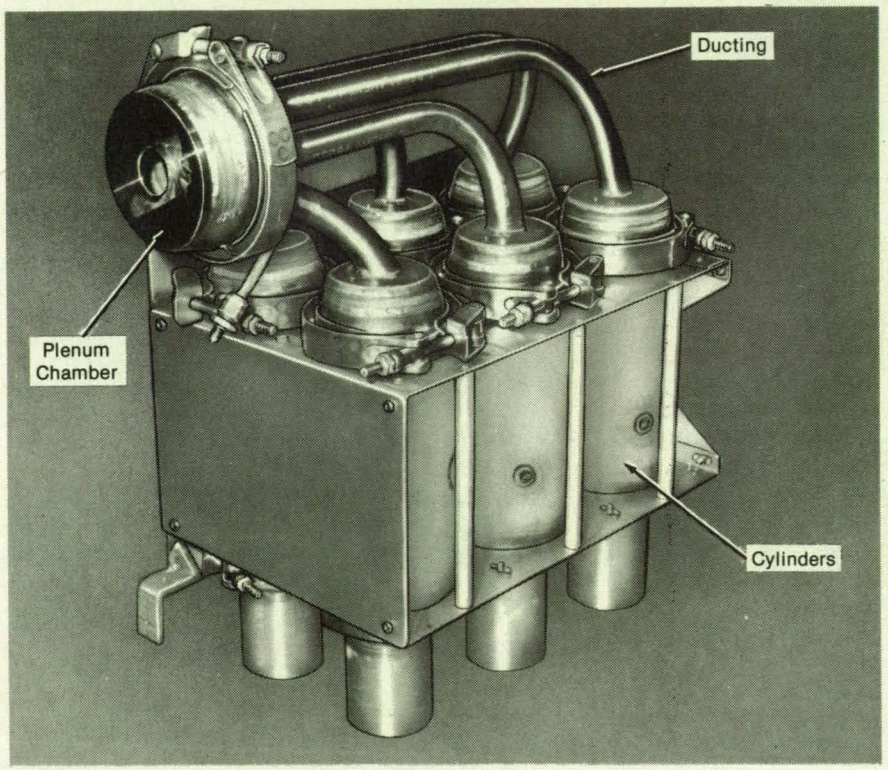

Figure 2. **Six Cartridges in the Cylinders** of each of two housings like this one generate smoke, which is sent through ducts to the surface of the airplane.

During nominal operation, smoke leaves the top of the cylinder through a duct of 0.93-in. (2.4-cm) inside diameter at a differential pressure that ranges from 2 to 10 psi (14 to 69 kPa). The ducts from all cylinders of a housing are connected to a common plenum chamber that is instrumented with a pressure transducer. If the pressure rises above 55 to 75 psi (380 to 520 kPa) because of blockage of a duct or an excessive rate of burning of a cartridge, rupture disks in each cylinder give way, venting the smoke out of the housing and to the outside through louvers on the lower surface of the airplane.

The housings are mounted in the gun bay of the airplane because the gun bay is already designed to withstand the release of hot gases from guns and because it is close to the locations from which it is desired to release smoke for aerodynamic studies. Smoke from each of the plenum chambers has been ducted up to 10 ft (2 m) through flexible polytetrafluoroethylene-lined hose to a rigid external stainless-steel duct.

The smoke generator provides for as many as six flow-visualization maneuvers during each flight (when using two cartridges per housing for each operation), each maneuver lasting about 30 s. Reliable operation of the system is limited to altitudes of 30,000 ft (9.1 km) or less. The smoke generator can be cleaned and made ready for a subsequent flight in several hours.

This work was done by David M. Richwine, Robert E. Curry, and Gene V. Tracy of **Ames Research Center**. *Further information may be found in NASA TM-4137 [N90-13372], "A Smoke Generator System for Aerodynamic Flight Research."*

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ARC-12698

Two-Pass, Diode-Pumped Nd:YAG Slab Laser Head

A simple design increases the efficiency of side pumping.

Goddard Space Flight Center, Greenbelt, Maryland

A neodymium/yttrium aluminum garnet (Nd:YAG) ring-laser head has been designed for compactness, simplicity, and increased efficiency for side pumping by diode lasers. The design calls for a slab (instead of a rod) of Nd:YAG. Slabs have been used before, but not in so simple and efficient a design.

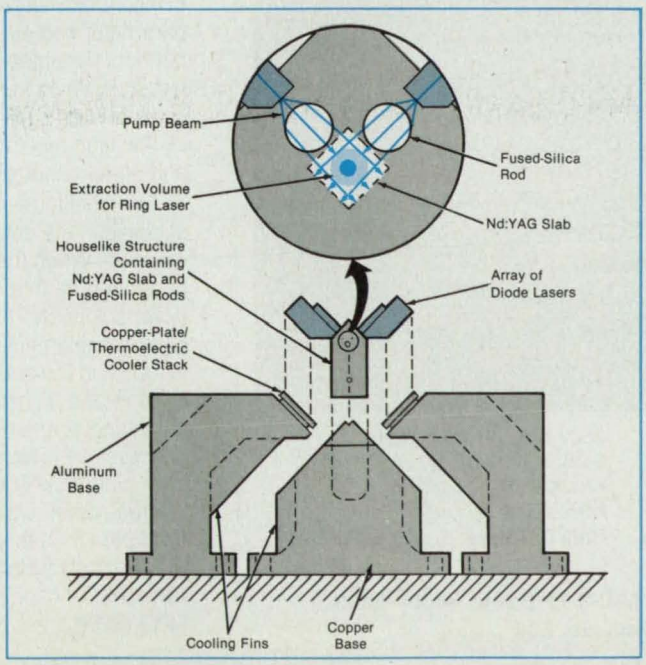
The laser head (see figure) includes two linear arrays of diode lasers, two fused-silica collimating rods, and the Nd:YAG slab. The slab is mounted on a finned copper block, which provides good thermal dissipation.

The arrays of diode lasers are single-bar units with output powers of 40 W during 200-μs pulses (amounting to 8 mJ of optical energy per pulse). Each array is tuned separately to the pump wavelength of 809 nm by adjusting its temperature with thermoelectric coolers and controllers. This wavelength is the peak absorption wavelength of Nd:YAG, and so this adjustment increases the pumping efficiency significantly.

The laser diode arrays produce laser pulses with a divergence angle of 35°. Consequently, the collimating rods are needed to couple these beams into the small lasing volume. These rods direct the light into the Nd:YAG crystal perpendicularly to the desired lasing axis. The diameter (2 mm) and position of the collimating rods were chosen to collimate the beams to a thickness of 1.5 mm, which equals the maximum diameter of the single-mode Nd:YAG laser beam according to the calculations for the ring laser resonator.

For maximum energy-extraction efficiency, the Nd:YAG slab was chosen to be a parallelepiped of 2 by 2 by 10 mm. All six sides of the slab are polished. The 2-by-2-mm faces were coated for antireflection at the output wavelength of 1,064 nm, two adjacent 2-by-10-mm faces were coated for antireflection at the pump wavelength of 809 nm, and the remaining adjacent 2-by-10-mm faces were coated for high reflection at 809 nm. The two adjacent pairs of coatings provide two double-pass pump paths at 90° to the ring-laser axis and 90° to each other, resulting in 84-percent absorption efficiency from the collimated pump beams. Overall, the lasing energy stored in the Nd:YAG slab is computed to be about 3.6 mJ per pulse.

Because the diodes can be run at a maximum pulse-repetition rate of only 100



This **View of the Laser Head** is along the ring-laser axis. The double-pass pump geometry increases the pumping efficiency. The overall configuration simplifies construction and alignment.

Hz, the maximum duty cycle is only 2 percent. Therefore, the circulation of air provides sufficient cooling for the slab-mount assembly. The laser-diode arrays are mounted on copper-plate/thermoelectric-cooler stacks, which are then mounted on 45° surfaces of an aluminum base with heat-dissipating fins. The complete assembly occupies an area of less than 3 by 7 inches on an optical table. A smaller, single-unit laser head is under construction due to the low heat-dissipation requirements and efficient pumping scheme.

This work was done by D. Barry Coyle of **Goddard Space Flight Center**. *For further information, Circle 1 on the TSP Request Card.*
GSC-13380

More-Precise Calibration of Polarimetric SAR

It is not necessary to assume reciprocity between the transmitting- and receiving-subsystem matrices.

NASA's Jet Propulsion Laboratory, Pasadena, California

An algorithm for the calibration of polarimetric synthetic-aperture-radar (SAR) data in the Stokes-matrix representation is more nearly exact than is a prior algorithm that extracts calibration parameters from the SAR image of a natural scene plus trihedral corner reflectors in the scene. In the derivation of the prior algorithm, it was assumed that the T and R matrices that represent the effects of the transmitting and receiving subsystems, respectively, of the radar system are reciprocal; in the derivation of the present algorithm, this assumption is not made.

Neglecting second- and higher-order terms in the crosstalk between the various channels of the radar system, the present algorithm yields an exact Stokes-matrix calibration. The present algorithm resembles the prior algorithm closely, except that it requires (1) the extraction of one additional parameter from the high-resolution raw SAR data in the scattering-matrix format before compression and transformation to the Stokes-matrix format and (2) a slight change in the subalgorithm that compresses those data.

The additional parameter is a ratio that expresses the amplitude imbalance between the HV and VH channels (where H and V denote horizontal and vertical polarization, respectively; the first of these letters in each pair denotes the nominal polarization of the receiving channel, and the second denotes the nominal polarization of the transmitting channel). The use of this parameter reduces the number of independent variables in the calibration problem from six to four, two of which are the crosstalk terms. This result applies equally in the high-resolution (scattering-matrix) and compressed (Stokes-matrix) formats.

The amplitude-imbalance parameter is supplied in the data header, prior to compression. When the compressed data are generated in this way, the more-nearly-exact solution to the calibration problem can be implemented easily. This solution is robust in the presence of nonreciprocity of R and T, high crosstalk, and poor balancing of channels — conditions that can give rise to significant errors when the prior algorithm is used.

This work was done by Anthony Freeman of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 142 on the TSP Request Card.*
NPO-18267

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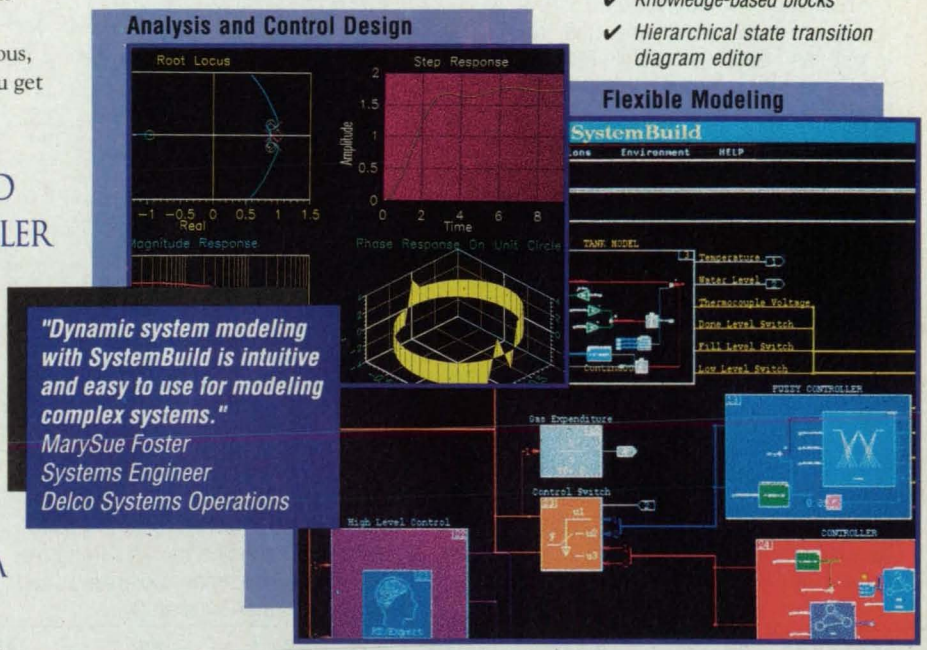

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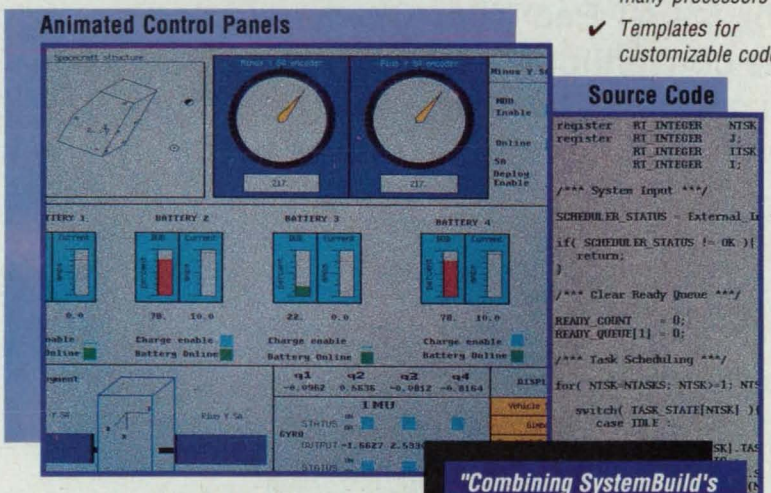

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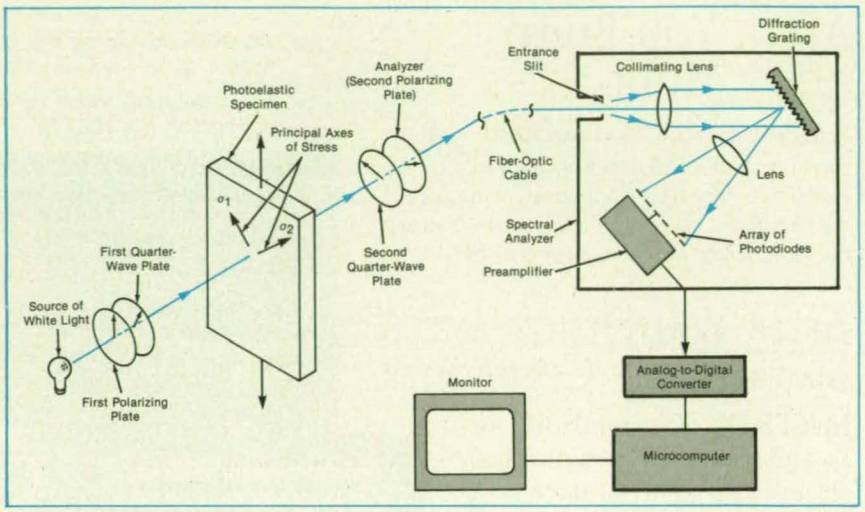
Spectral-Content Readout of Stress-Induced Birefringence

The spectrum of transmitted light indicates stress in a sensor or specimen.

Ames Research Center, Moffett Field, California

An experimental advanced photoelastic apparatus has demonstrated the feasibility of analysis of the spectrum of transmitted light to quantify birefringence (and, therefore strain and stress) in a transparent specimen. Although photoelastic analysis of stress is an old technique, heretofore it has been used mainly to generate qualitative or semiquantitative visible maps of stress and strain. By augmenting conventional photoelastic analysis with spectral sensors and automating it with computer control and processing of data, the technique can be made more versatile and useful. Potential uses include the measurement of stresses in optical fibers and transparent materials in general.

In the experimental apparatus (see figure), the specimen is placed between polarizing and quarter-wave plates and illuminated with white or other nonmonochromatic light. The light that emerges from the analyzer (the second polarizing plate) passes through an entrance slit and a collimating lens onto a diffraction grating. The resulting spectrum reflected from the grating strikes an array of photodiodes. The outputs of the photodiodes are fed through a preamplifier and digitized for analysis.



Birefringence Due to Stress in the photoelastic specimen varies with the wavelength of the illumination. The retardation due to birefringence and, therefore the stress in the specimen, can be deduced from the measured transmission as a function of wavelength.

From the basic principle of the polariscope it can be shown that the transmission, T, of the specimen, polarizers, and quarter-wave plates is given by

$$T(\delta,\lambda) = [\sin^2(\pi\delta/\lambda)]\{1 - [\sin^2(2\alpha)][\sin^2(2\varepsilon)]$$

where λ is the wavelength of light, δ is the relative retardation between wavefronts containing two mutually perpendicular polarizations, and is proportional to the

birefringence induced by stress in the specimen, α equals the (usually unknown) angle between one of the principal axes of the stress and the first quarter-wave plate, and ε is a (usually small) correction phase that is needed when the retardation in the quarter-wave plate is not exactly a quarter wavelength (i.e., when it is used at other than its nominal wavelength). When α is unknown, one can minimize the error by setting $\sin^2(2\alpha) = \frac{1}{2}$.

The digitized outputs of the photodiodes are processed to obtain the transmission spectrum. The computer then searches for the particular δ for which this spectrum best fits the equation for $T(\delta, \lambda)$. The stress in the specimen can then be deduced from the known proportionality between the stress, thickness, and δ.

This work was done by Alex S. Redner and Arkady S. Voloshin of Strainoptic Technologies, Inc., for **Ames Research Center**. *Further information may be found in NASA CR-179430 [N88-20673], "Spectral Contents Readout of Birefringent Sensors."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12220

Full-Surface Phasing of a Segmented Mirror

Techniques based on physical and on geometrical optics would be applied jointly.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed combination of measuring and computing techniques would be used to determine the deviation of the surface of a large, segmented telescope from the ideal surface figure and to compute adjustments in the alignments of the segments to obtain the optimum available compensation for the deviations. The combination method incorporates the conventional Shack–Hartmann technique, which is based on geometrical optics, and the modified Shack–Hartmann technique, which is based on physical optics. The combination method has been tested by computer simulation, using the Keck astronomical telescope as a mathematical model.

Figure 1 illustrates the Shack–Hartmann test. Light reflected from the mirror under test is relayed via a collimated beam to an array of lenslets. Each lenslet represents a small portion of the surface under test. In the conventional Shack–Hartmann technique, each lenslet represents a portion of one of the segments of the reflector and focuses light from that portion onto a spot on an area detector. The location of the centroid of each spot is measured, and the deviation of that spot from its intended location is taken as a measure of the deviation of the slope of the corresponding portion of the segment from the intended slope.

In the conventional Shack–Hartmann technique, the strategy for alignment is to adjust the tilts of the segments in such a way as to minimize the root-mean-square deviation of the locations of all the centroids from the intended locations. This strategy optimizes the tilts but does not assure the desired continuity of phase among segments because the centroid measurement is insensitive to piston errors (errors of displacement along the optical axis).

In the modified Shack–Hartmann technique, each lenslet is positioned to image a small area that straddles the boundary between two adjacent segments. In this configuration, each lenslet produces a diffraction image of a star or other far-field source. The diffraction pattern is affected by interference between the wave fronts

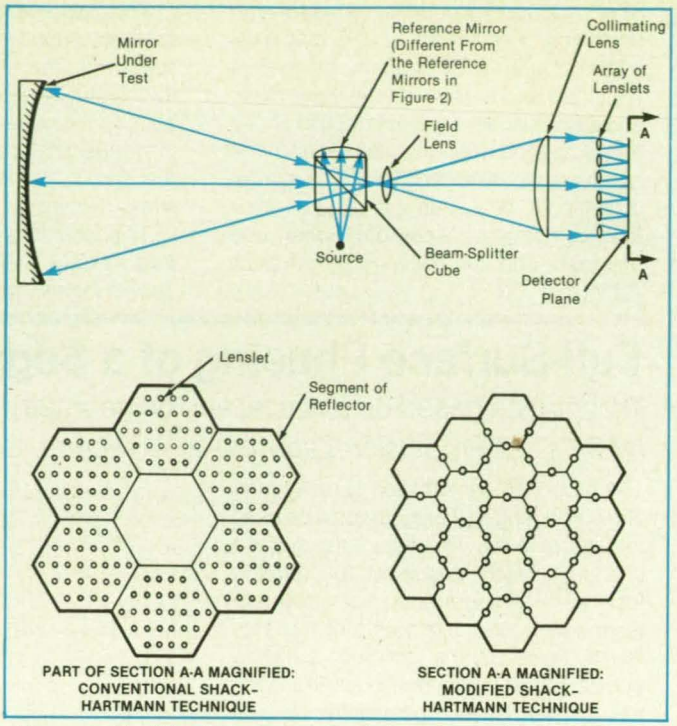


Figure 1. The **Shack-Hartmann Technique** is used to test a large, segmented mirror like that of an astronomical telescope.

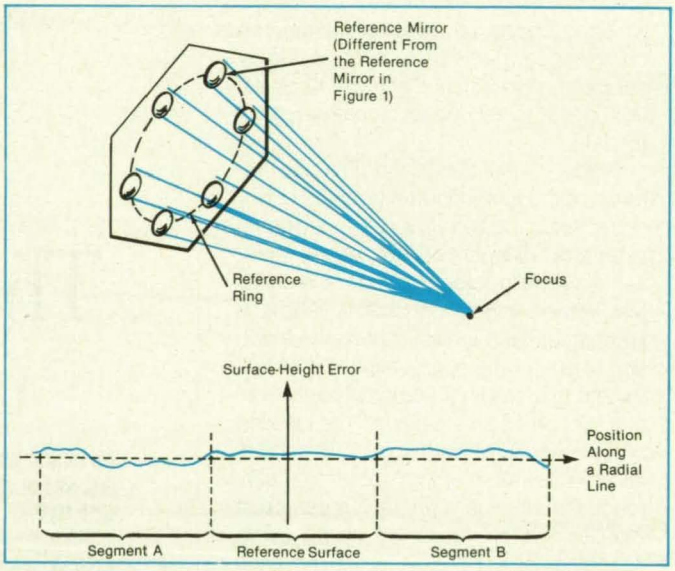


Figure 2. **Reference Mirrors in a Ring** define a reference surface for measurement and adjustment of the segments of the reflector under test.

reflected by the adjacent segments and can be analyzed to determine the piston error between the two segments at that location.

In the combination technique, the central hole of the segmented mirror would be occupied by a reference surface defined by six small reference mirrors arranged in a ring (see Figure 2). These mirrors would be manufactured to the desired surface figure with high precision, then mounted and aligned for precise phase at the focal spot (for a paraboloidal mirror) or center of curvature (for a spherical mirror).

First, the tilts of the segments would be adjusted with respect to those of the reference mirrors by the conventional Shack-Hartmann technique. Next, the edges of the panels would be brought into phase with each other and with the reference mirrors by the modified Shack-Hartmann technique. Then, returning to the conventional Shack-Hartmann technique, the deviation in slope with respect to the ref-

erence surface would be measured across the full surface, and the slope information thus obtained would be used to compute the variation in surface height with respect to that of reference mirrors. Because the edges of the segments would be phased, the height would be continuous and could be mapped over the whole surface.

Finally, compensating tilt and piston adjustments would be computed for each segment to minimize the overall variation in surface height with respect to the reference surface. The piston and tilt adjustments would then be performed on each segment. It is important to note that the method cannot be applied iteratively because continuity of the surface is required at the intermediate steps, and once the adjustments are performed, the surface may no longer be continuous.

This work was done by Paul K. Manhart of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 74 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel. NASA Resident Office-JPL [see page 20]. Refer to NPO-18095.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Thermodynamic Aspects of Heat-Pipe Operation

A new analysis shows why many heat pipes have not performed as well as expected.

A report discusses thermodynamic aspects of the principles of operation of heat pipes. Heretofore, designs of heat pipes have been based on a classical theory that fails to take account of these aspects. Many heat pipes designed according to the classical theory have failed to perform as well as expected, some transporting heat at rates as much as an order of magnitude below design rates. This report shows that the thermodynamic aspects account for many of the discrepancies.

In the classical theory, it is assumed that the flow of vapor in the vapor space and of liquid in the wick of a heat pipe are maintained by capillary suction in the wick. It is also assumed that the heat pipe is isothermal or nearly so. In the new analysis, it is recognized that the capillary action assists, but does not drive, the flow and that the circulation of working fluid is forced by a pumping process based on the conversion of thermal energy into kinetic energy in a thermodynamic cycle. This view does not entail an assumption of isothermality; on the contrary, it is assumed that the heat-pipe pumping cycle, like all thermodynamic cycles, is driven by differences of temperature and, therefore, the evaporator end of the heat pipe must be hotter than the condenser end if the heat pipe is to transport heat.

By invoking a simple equation for the vapor pressure as a function of saturation temperature and using water as an example of a working fluid, it is shown that the small difference between the vapor pressures at the evaporator and condenser, which difference is responsible for the pumping action, is proportional to the average vapor pressure and to the difference between the temperatures at the evaporator and condenser. According to this proportionality, the higher the vapor pressure is in a given case, the lower is the temperature drop required to obtain a pressure drop necessary for pumping. This finding is consistent with experience that shows that the same heat pipe containing the same fluid can carry a greater thermal load at a higher temperature.

To maintain the flow of liquid in the wick from the condenser back to the evaporator, it is necessary to maintain a pressure gradient that, in turn, requires a difference between the pressures (and, therefore, the temperatures) of the liquid and vapor at the same axial position in the heat pipe. This, in turn, requires a radial thermal gradient, contrary to the classical assumptions of isothermality and adiabaticity in the portion of the heat pipe between the evaporator and condenser. Only by permitting a radial temperature gradient commensurate with the pressure gradient can one prevent liquid from vaporizing in the wick. Thus, it is fortunate that the insulation that is usually placed around this portion of a typical heat pipe is not perfect and usually allows the required radial thermal gradient to exist.

This work was done by Robert Richter of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Thermodynamic Aspects of Heat Pipe Operation," Circle 150 on the TSP Request Card.*

NPO-18148

Materials

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Rugged Low-Resistance Contacts to High-T_c Superconductors

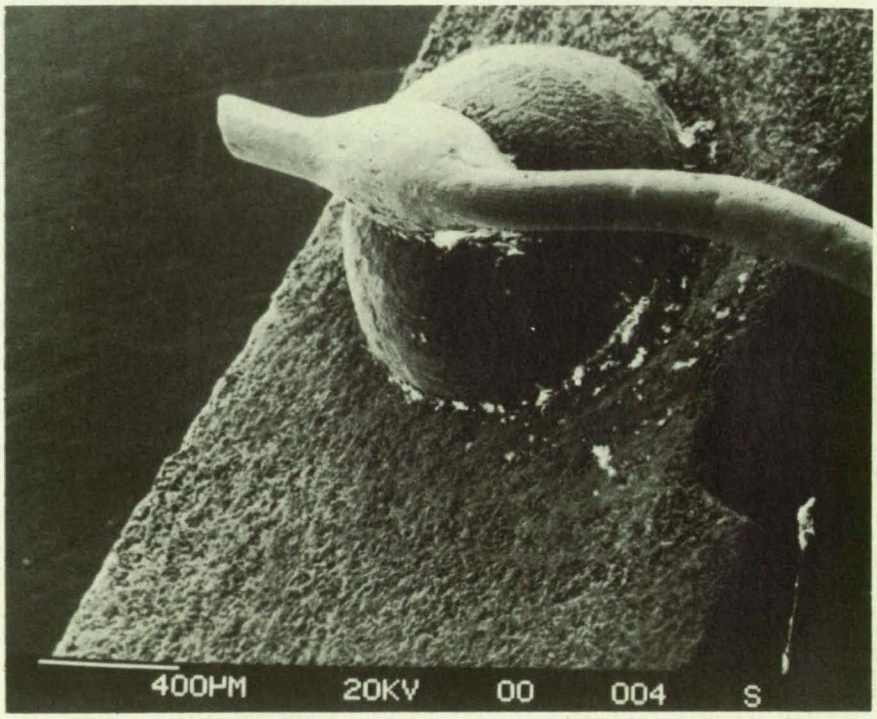
Gold beads provide low electrical resistance and high shear strength.

Langley Research Center, Hampton, Virginia

Since the new superconductors that have high critical temperatures (T_c's) are ceramics, the need to make electrical contact to these novel materials presents a challenge. While silver-paste and pressure contacts can be used to measure the resistive transition, the inability of such contacts to carry large currents without being destroyed or producing excessive noise makes them unsuitable for use in determining large critical currents directly or in high-current applications. Heretofore, success in making low-resistance, high-current contact to high-T_c materials by use of gold has been very limited. However, a newly developed technique that involves the use of gold makes it possible to fabricate low-resistance contacts with rugged connections to high-T_c superconductors.

In the new technique, gold is diffused into a specimen of the superconducting material by melting gold beads onto the surface of the specimen, making strong mechanical contacts. The first step is to place small squares of gold foil on the surface of the specimen, which is typically a shaped resistivity specimen that has been cut from a pellet of the superconducting material that has been fully treated in oxygen. The specimen is heated to 1,065 °C in air for about 1 hour, during which the gold melts and diffuses into the pores of the specimen. The specimen is removed from the oven once it has cooled to about 900 °C.

At this point, the gold bead that is formed on melting is slightly oxidized and firmly connected to the specimen. However, the contact resistance is quite high (of the order of kilohms). Some of the oxygen has been lost from the specimen during heating in the oven, and retreatment in oxygen is necessary. It is then easy to solder external leads to the beads by conventional methods, making good electrical contact (see figure).



This **Scanning Electron Micrograph** shows an electrical lead soldered to a gold bead contact on a superconducting substrate.

In a demonstration of the technique, rugged low-resistance contacts were made to specimens of the high-T_c superconductor $YBa_2Cu_3O_x$. After retreatment of the specimens in oxygen, contact resistances of less than 50 $\mu\Omega$ were measured. A direct current of about 5 A was passed through the contacts, without heating, while the specimen remained in the superconducting state at 20 K. The shear strength of the gold bead contacts is greater than that of epoxy or silver paste. Such sturdy contacts will be of practical use in high-current-carrying applications of the new high-T_c materials, including superconducting magnets, long-wavelength sensors, electrical ground planes at low temperatures, and efficient transmission of power.

This work was done by Randall Caton and Raouf Selim of Christopher Newport College, Charles E. Byvik of **Langley Research Center,** *and A. Martin Buoncristiani of the National Research Council. For further information, Circle 95 on the TSP Request Card.*

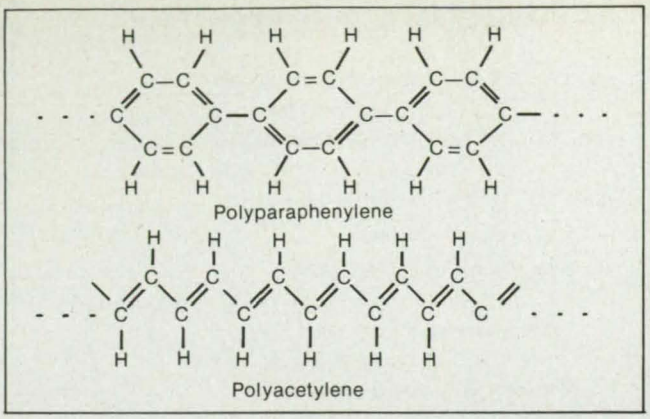
LAR-13964

Making Conductive Polymers by Arc Tracking

An experimental technique takes advantage of a heretofore undesirable phenomenon.

Marshall Space Flight Center, Alabama

An experimental technique for the fabrication of electrically conductive polymeric filaments is based on arc tracking, in which an electrical arc creates a conductive carbon track in a material that initially was an insulator. Arc tracking is usually caused by an electrical short circuit. Heretofore, arc tracking has been regarded as



Electrically Conductive Polymeric Structures made by arc tracking are aligned along the wire on which they are formed. This alignment is particularly suited to high conductivity and would be desirable in materials intended for testing as candidate superconductors.

an undesirable phenomenon because the conductive track remains after the arc power is shut off and further damage occurs when power is reapplied, eventually rendering the insulation useless.

Polyimide insulation on wires is particularly vulnerable to arc tracking, which can occur at relatively low voltages and sustaining currents. The experimental fabrication technique exploits this effect. To demonstrate the technique, a pair of wires of 28 American Wire Gauge (0.321-mm diameter) insulated with polyimide was cut to a length of 15 ft (4.6 m) and connected to a 28-V, 5-A power supply. The wires at the end remote from the power supply were then brought into contact, causing an arc to propagate along the wires back toward the power supply. The arc and shorted wires drew a current of 4 to 10 A for about 30 s.

The resulting strip of pyrolized plastic between the wires had a fibrous form and was found to conduct electricity even after the wires were removed. It appears that pyrolysis in the arc turns the polyimide into conductive graphitic carbon and/or a polymer with a structure intermediate between that of graphite and that of polyimide.

The essential feature of such a conductive carbon-based material is the repeating C=C–C unit found in such electrically conductive plastics as polyacetylene and polyparaphenylene (see figure). When the material is subsequently treated by addition of positive ions (e.g., sodium) or negative ions (e.g., bromine) at the ratio of about one such "dopant" ion per 12 to 15 carbon atoms, the material becomes highly conductive. A "plastic wire" made in this way could have a conductance equal to or greater than that of a copper wire but would weigh considerably less. The original copper wire could be removed after pyrolysis or allowed to remain as a reinforcement for the conductive polymeric filaments.

This work was done by Alfred F. Daech of Martin Marietta Corp. for **Marshall Space Flight Center**. *For further information, Circle 115 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28529.

Polyethylene Glycol Propionaldehydes

These compounds are stable in water and reactive toward amines.

Marshall Space Flight Center, Alabama

A new class of compounds derived from polyethylene glycol (PEG's) — namely, PEG-propionaldehydes — offers two important advantages over other classes of PEG aldehyde derivatives: the compounds in this class exhibit selective chemical reactivity toward amino groups and are stable in an aqueous environment. Unlike PEG-acetaldehydes, these compounds resist decomposition via aldol condensation in the presence of base, and they are much more reactive toward amines than are PEG-benzaldehydes.

PEG's and derivatives thereof can be used to couple a variety of other molecules, for example, to tether protein molecules to surfaces. The biotechnical and biomedical applications can include partitioning of two phases in aqueous media; immobilization of such proteins as enzymes, antibodies, and antigens; modification of drugs; and preparation of protein-rejecting surfaces. In addition, surfaces coated with PEG's and derivatives thereof can be used to control wetting and electroosmosis.

A PEG-propionaldehyde containing sulfur was prepared in the sequence of reactions shown in the figure. The intermediate acetal and the product aldehyde were identified from their nuclear-magnetic-resonance spectra. Although it is not expected that having sulfur, rather than oxygen, as the linking atom between the polymer and aldehyde will be of consequence, possible synthetic routes to PEG-propionaldehydes without sulfur can be devised.

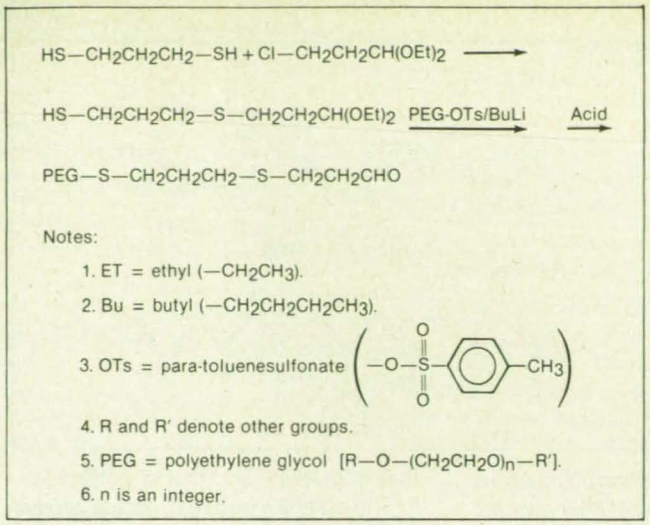
The experimental PEG-propionaldehyde

appears to be ideal for use in modifying proteins: Reductive amination proceeds rapidly under a variety of conditions. In a typical experiment, 1 part by weight of protein was reacted with 4 parts by weight of the experimental PEG-propionaldehyde in the presence of sodium cyanoborohydride for 1 hour at room temperature in pH 9 borate buffer, followed by dialysis against phosphate-buffer saline. As a result, a significant fraction of the available lysines were modified. For example, the antibody against alkaline phosphatase (antialkaline phosphatase) was 38 percent modified, and the antibody against human red blood cells (antihuman RBC's) was 28 percent modified.

Another potential application of PEG-propionaldehyde is in coupling to aminated surfaces. For example, it is readily coupled to aminated glass in water at room temperature; reduction of the imine linkage is accomplished by use of sodium cyanoborohydride, described for the protein reactions. [If a difunctional PEG aldehyde is used (e.g., PEG 4000 dialdehyde), the aldehyde can first be coupled to the surface and then to some other molecules (such as those of a protein) to link those molecules to surfaces.] The major advantage of PEG-propionaldehyde for this surface application is that it can be applied in water. Thus, one can work with surfaces (such as many organic polymers) that would be damaged by the dry organic solvents most suitable for many other water-sensitive, active PEG's.

This work was done by Joe M. Harris and Mohammad R. Sedaghat-Herati of the University of Alabama in Huntsville and Laurel J. Karr of **Marshall Space Flight Center**. *For further information, Circle 19 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-26127.



This **PEG-Propionaldehyde** containing sulfur is prepared by this sequence of reactions carried out in dimethylsulfoxide.

New Cross-linkable Polyimides

Methyl groups cross-link in air at 275 °C or upon ultraviolet irradiation to form insoluble polyimides.

Langley Research Center, Hampton, Virginia

Polymides are condensation polymers commonly synthesized by the reaction of aromatic dianhydrides with aromatic diamines. In a typical case, the intermediate polyamide acid is either thermally or chemically cyclodehydrated to form the polyimide. Methyl side groups on polyimides have been shown to increase the solubilities and to affect the glass-transition temperatures and crystalline melting temperatures. Polyimides containing methyl substituents are potentially useful in microelectronic applications because they undergo cross-linking photochemical reactions when exposed, for example, to ultraviolet radiation.

A series of new methyl-substituted polyimides containing carbonyl and ether connecting groups between the aromatic rings were prepared from the reactions of three aromatic dianhydrides with methyl-substituted diamines in which carbonyl and ether connecting groups lie between the aromatic rings. The diamines were prepared by the reactions of 3-methyl-4-aminophenol and 3,5-dimethyl-4-aminophenol with bis(4-fluorobenzoyl)-terminated compounds in the presence of potassium carbonate.

The methyl-substituted polyimides are amorphous, and when the polyamide acids are converted to the polyimides under conditions that prevent thermal cross-linking, the resulting polyimides are much more soluble than are similar polyimides that do not contain methyl substituents. These sol-

uble, thermally processable polyimides exhibit high glass-transition temperatures and good mechanical properties. Upon exposure to ultraviolet radiation or temperatures above 275 °C in air, the methyl-substituted polyimides cross-link to form insoluble polymer networks.

These new materials may be particularly useful in electronics and microelectronics; for example, as high-temperature coats for printed-circuit boards, for photoresist applications, and possibly for printing and membrane applications. These materials may also be useful as films, adhesives, and composite matrices.

This work was done by Paul M. Hergenrother of **Langley Research Center** *and Stephen J. Havens of Planning Research Corp. For further information, Circle 156 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14351.

High-Temperature Treatments for Polyimide/Graphite Composite

Two treatments could enhance thermo-oxidative and structural stabilities.

Lewis Research Center, Cleveland, Ohio

The combination of (1) an inert-gas heat treatment and (2) coating with a material impermeable by oxygen has been proposed to increase the thermo-oxidative and high-temperature structural stabilities of composite materials made of graphite fibers in matrices of PMR-15 polyimide. This proposal is the result of one in a continuing series of experimental studies directed toward the development of lightweight matrix/fiber composites for use in aircraft engines, wherein the composites are expected to be exposed to maximum operating temperatures between 371 and 427 °C.

With regard to structural stability, the major questions are whether a composite retains sufficient strength at the intended operating temperature and, in particular, whether the glass-transition temperature (T_g) of the composite exceeds the operating temperature so that the composite remains elastic (rather than becoming rubbery) at the operating temperature. With regard to thermo-oxidative stability, the major questions are whether an oxygen-excluding coating material can be developed and, if so, whether the composite remains thermally stable enough that no thermal degradation occurs after the coat is applied. In this regard, one must also ask whether the release of gaseous products of pyrolysis would disrupt the coat, thereby allowing eventual penetration by oxygen.

This study addressed the outgassing, retention-of-strength, and T_g aspects of the problem. Specimens of PMR-15/graphite-fiber composites were aged in a nitrogen atmosphere at various temperatures from 371 to 427 °C and for various times ranging up to a few hundred hours. Changes in dimensions, fractions of weight lost in pyrolysis, and changes in the T_g's of the specimens were measured. In addition, the specimens were examined for cracking, warping, and other signs of damage caused by the buildup of residual stresses caused, in turn, by changes in the densities of constituents.

The results of these experiments indicate that T_g and short-time strength at high temperature (see table) are both increased by the aging treatment. Furthermore, no cracking, warping, or microscopic surface porosity was found. It appears that composites thus treated would be strong enough for short-time structural use at 371 °C. A suitable oxygen-excluding coat would be necessary for long-time structural use.

	Room Temperature		371 °C	
	Flexural Strength, MPa	Modulus of Elasticity, GPa	Flexural Strength, MPa	Modulus of Elasticity, GPa
Not Aged	1,419	148.2	482.6	84.1
Aged	1,184.6	148.2	1,165.3	144.8

The **Strength and Stiffness** of a PMR-15 polyimide/graphite-fiber composite at a temperature of 371 °C are increased significantly by aging for 400 hours in N_2 at a temperature of 371 °C.

This work was done by Kenneth J. Bowles and Carl Lowell of **Lewis Research Center**. *Further information may be found in NASA TM-100922 [N88-25483], "A Thermally Modified Polymer Matrix Composite Material With Structural Integrity to 371 °C."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

This invention has been patented by NASA (U.S. Patent No. 4,992,528). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center [see page 20]. Refer to LEW-14734.

Making High-Temperature Superconductors by Melt Sintering

Relatively thick films of oriented bulk superconductive material have been produced with thicknesses up to 1 mm and areas up to 1 cm^2.

Marshall Space Flight Center, Alabama

A melt-sintering technique has been applied to the $YBa_2Cu_3O_{7-x}$ system and to the Bi/Ca/Sr/Cu-oxide system to produce highly oriented bulk high-temperature-superconductor materials extending to macroscopically usable dimensions. The processing requires relatively inexpensive and simple equipment, compared with that normally used to produce thin films of these superconductors. Because the critical current can be two orders of magnitude greater in the crystal **ab** plane than in the crystal **c** direction, a high degree of orientation can greatly enhance the critical current in these bulk materials, making them much more suitable for many proposed applications.

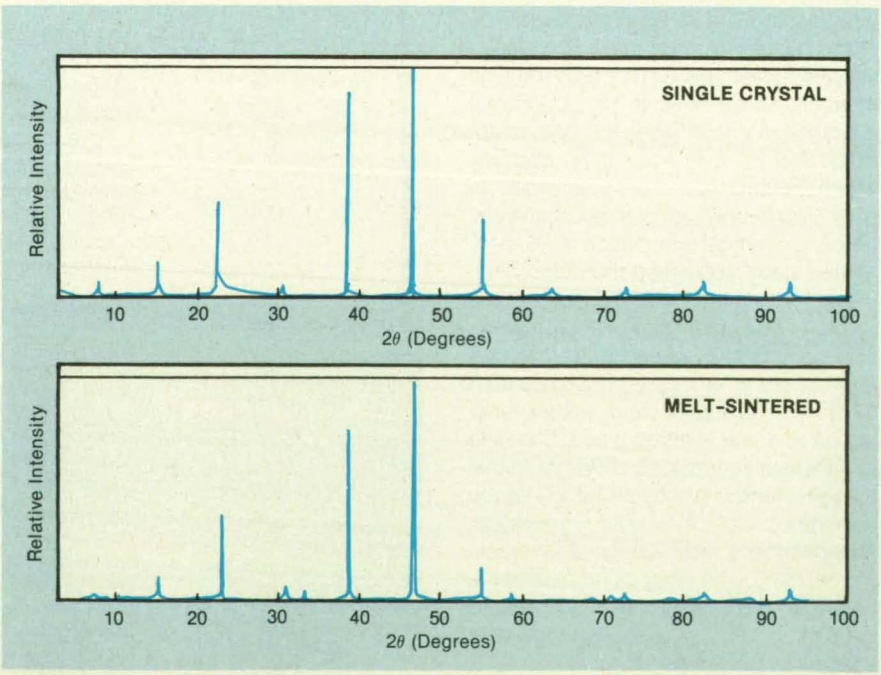
The preparation of oriented superconductive material in the $YBa_2Cu_3O_{7-x}$ system is difficult because of the tendency toward incongruent melting in this system. Processing begins with the mixing of Y_2O_3, $BaCO_3$, and CuO powders in molar ratios such that the Y:Ba:Cu ratio is 1:2:3. The mixture of powders is then slowly heated from a preheat temperature to the sintering temperature to ensure complete calcination, especially the liberation of CO_2 from the $BaCO_3$. The slow heating also promotes the homogeneous growth of the $YBa_2Cu_3O_7$ phase, inhibiting the formation of the undesired Y_2BaCuO_5 and $BaCuO_2$ phases. The oxygen content, $7-x$, has a usual minimum of about 6.5 and is exchanged with the atmosphere, resulting in a value between 6.5 and 7.0. The heat treatment can ensure a value close to 7.0.

The heat treatment begins with preheating at controlled rates to 900 °C. The material is held at this temperature for 15 h, then cooled to room temperature at the same controlled rates. Next, the material is sintered for 15 to 60 h at 927 °C, then cooled at controlled rates to room temperature. The material is characterized by x-ray diffraction after the preheat or sintering step to determine whether the pure $YBa_2Cu_3O_7$ phase has been formed.

The material is then melt-sintered for 15 to 50 min at a temperature of, typically, 1,040 to 1,060 °C. The melt-sintered material is then cooled rapidly (20 to 25 °C/min) to about 1,000 °C (to minimize the time above the peritectic temperature of 1,025 °C), then slowly (0.3 °C/min) to 970 °C (to promote additional orientation of the material), then rapidly (10 °C/min) to 900 °C (to prevent additional growth of undesired phases), then slowly (2 to 5 °C/min) to room temperature (to allow for the diffusion of oxygen into the material in the temperature range in which uptake of oxygen is maximum). Finally, the material is annealed in the temperature range of 450 °C to 525 °C.

The figure shows x-ray diffraction scans of melt-sintered and single-crystal specimens of $YBa_2Cu_3O_{7-x}$. The single crystal represents an ideal thick film in the preferred orientation, in which the **c**-axis is perpendicular to the surface. These scans show that the melt-sintered specimen has the same orientation; that is, only reflections characteristic of a high degree of **c**-axis orientation are present.

The preparation of superconductive materials in the Bi/Ca/Sr/Cu-oxide system is different and somewhat easier because under the proper conditions, congruent melts can be obtained. Experiments have involved Bi/Ca/Sr/Cu oxides in which the atomic ratios of these metals were nominally 2:2:0:1, 2:2:1:2, and 2:2:2:3, except that in some specimens, 10 or 15 percent Pb or 5 percent Sb have replaced the corresponding atomic proportions of Bi in the aforementioned nominal stoichiometries. The melt-sintering effect observed in this material system is as follows: As the temperature increases toward the melting point, the 2:2:0:1 phase is formed first, followed by the 2:2:1:2 phase, followed by the 2:2:2:3 phase. As the temperature increases beyond the melting point, the desired 2:2:2:3 phase is formed first, followed by the undesired 2:2:1:2 and 2:2:0:1 phases, respectively. These phases are now found in a highly **c**-axis oriented form. The substitution of Pb or Sb for Bi in the amounts specified above greatly enhances the melt-sintering effect. In particular, the intensities of those x-ray diffraction peaks that indicate the desired type and degree of orientation can be an order of magnitude higher



X-Ray-Diffraction Scans of a single crystal of $YBa_2Cu_3O_{7-x}$ (above) and of a melt-sintered specimen of the same material (below) indicate that both have the same high degree of **c**-axis orientation.

in specimens that contain Sb than they are in average melt-sintered specimens that do not contain Sb. As in the yttrium 1:2:3 system, the melt-sintering effect is observed in macroscopically bulk portions of specimens.

This work was done by John P. Golben of UAH Research Institute for **Marshall Space Flight Center**. *For further information, Circle 6 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-26142.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Characteristics of Superplastically Formed Ti-6242 Sheet

A near-alpha titanium alloy is candidate for high-temperature structural airframe applications.

Research on the advanced processing of metals is being conducted at the NASA Langley Research Center to develop improved methods of forming and joining with the potential of reducing the weights and costs of future aerospace structures. Studies have demonstrated that superplastic forming (SPF), superplastic forming/weld brazing (SPF/WB), and superplastic forming/diffusion bonding (SPF/DB) are viable processes for fabricating titanium structures that exhibit improved efficiency. The relative simplicity of the SPF process alone promises to make a substantial impact on future structural components.

Considerable interest in the aerospace industry has been focused on the near-alpha titanium alloy Ti/6Al/2Sn/4Zr/2Mo (Ti-6242). This alloy, with room-temperature mechanical and physical properties similar to those of the popular Ti/6Al/4V alloy, is being considered for use in high-temperature structural airframe applications because of its superior properties at temperatures as high as 1,000 °F (538 °C). Design criteria for these new applications make it paramount that high-temperature tensile and creep behavior be understood. This research characterizes selected mechanical properties of Ti-6242 sheets in the SPF condition, both with and without heat treatment, and compares the results with those obtained on as-received material.

The as-received properties of the sheets used in this research were found to vary considerably due partially to the mix of mill-anneal and (mill) duplex-anneal conditions. The tensile properties of SPF Ti-6242 material are not the same as those in the published data base for Ti-6242 sheet. The room-temperature tensile strength, yield strength, and elongation observed in this research all indicate a trend toward smaller values with increasing SPF strain and time at temperature. Approximately 10 percent of the strength of the parent material is lost after superplastic forming to 700 percent. The yield strength at 600 °F (316 °C) was found to decrease approximately 13 percent. This loss in tensile properties was observed only at temperatures up to 800 °F (427 °C). No difference between the tensile properties of as-received and SPF-strained materials was observed at 1,000 °F (538 °C). A postforming duplex-anneal heat treatment was found not to affect tensile properties beneficially.

The creep strength of Ti-6242 sheet was found to be enhanced by the SPF process, with the greatest improvement observed at 1,000 °F (538 °C). An unexpected reduction in the creep resistance of SPF sheet was brought about by the duplex-anneal heat treatment. The growth of grains in Ti-6242 during SPF processing at 1,650 °F (899 °C) was found to vary linearly with time.

The information derived from this research should prove useful to the aerospace community for designing and manufacturing Ti-6242 structures and structural components.

This work was done by Dick M. Royster of **Langley Research Center** *and William A. Ossa of Planning Research Corp. Further information may be found in NASA TP-2674 [N87-20407], "Material Characterization of Superplastically Formed Titanium (Ti-6Al-2Sn-4Zr-2Mo) Sheet."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LAR-14304

Viscoelastic Response of a Highly Filled Polymer

The behavior under biaxial stretching was measured and characterized theoretically.

A report describes experimental and theoretical studies of the nonlinear viscoelastic response of an elastomeric binder material filled with small particles of a different material. The purpose of these studies was to characterize the response with sufficient accuracy for use in designing parts that may be subjected to high strains. Such a characterization requires at least measurements of responses to biaxial stresses and the reduction of the experimental data to a stored-energy-density function.

The specimen was a sheet of the material 2.5 in. (6.35 cm) square with a 0.5-in.-wide (1.27-cm-wide) border 0.36 in. (0.91 cm) thick and a central 1.5-in. (3.81-cm) square section 0.18 in. (0.46 cm) thick. The border was perforated with six holes on each edge to engage strain-gauge-instrumented hooks through which tensile loads were applied by a biaxial testing machine and measured. The central square section was marked with circles and a square grid, which were observed to measure the strains.

The specimen was subjected to stress-relaxation tests, from which it was determined that the time-dependent part of the relaxation response could be approximated by a function that is independent of strain and biaxiality. Consequently, it was determined that the isochronal data from the stress-relaxation tests could be used to determine the stored-energy-density function.

The material was found to behave quite complicatedly under biaxial deformations. It was conjectured that this behavior may be caused by dewetting (that is, separation of the binder from the filler). Because the nature of dewetting would depend on the biaxial-stress field, one of the consequences of this conjecture is that the biaxial stress-vs.-strain response would depend not only upon the response of the binder and on the interaction between the binder and filler but also on the degree and nature of dewetting.

Even without knowledge of the complicated mechanisms of binder/filler interactions and dewetting, it was found to be possible to describe the behavior of the material in terms of a stored-energy function; more specifically, a symmetric strain-energy function that is the sum of three identical functions, one for the stretch ratio (length when stretched/length before stretching) along each of the three principal coordinate axes. The multiaxial response predicted by use of this function agreed well with the experimental data at stretch ratios as high as 1.16.

This work was done by Steven T. J. Peng and Robert F. Landel of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Nonlinear Viscoelastic Response of Highly Filled Elastomers Under Multiaxial Finite Deformation," Circle 135 on the TSP Request Card.*
NPO-18223

Properties of High-Performance Thermoplastics

Sixteen of the principal thermoplastics used to fabricate high-performance composites are reviewed.

A report presents a review of the principal thermoplastics (TP's) used to fabricate high-performance composites. The tensile and fracture-toughness properties, glass-transition temperatures (T_g), crystalline melt temperatures (T_m), and approximate processing conditions are listed. Mechanical properties of carbon-fiber composites made from many of these TP's are given. These include flexural, longitudinal tensile, transverse tensile, and in-plane shear properties as well as short-beam-shear and compressive strengths and interlaminar fracture toughnesses. Attractive features and problems involved in the use of TP's as matrices for high-performance composites are discussed.

This review is especially appropriate now because of the heavy emphasis being placed on the development and application of the TP's as matrices for fiber-reinforced composites on such advanced Air Force weapons systems as the Advanced Tactical Fighter (ATF). The data included in this paper were obtained from a large number of sources, mostly suppliers of materials.

Sixteen principal TP's considered as candidates for fabrication of high-performance composites are presented along with names of suppliers, T_g, T_m (for semicrystalline polymers), and approximate maximum processing temperatures. Five are polyarylene ether or sulfide polymers, three of which are semicrystalline. Three are amide or amideimide compositions. Four are polyimides. Three polysulfones and one polyester complete the list. Fifteen of these TP's are heavily aromatic in character. In eleven of these materials, the chemical flexibilizing groups between phenyl rings in the backbones of the molecules include isopropylidene, carbonyl, oxygen, sulfur, and sulfone.

A summary is given of the tradeoff in properties between thermosets and TP's as composite matrices. The one key element that dominates the tradeoff list and can tip the balance to TP's is that of the costs of fabrication. However, the potential for low-cost manufacturing of TP's remains to be demonstrated. Very little flight experience, even with TP secondary structures, exists to gauge either durability, requirements for maintenance, or tolerance to damage. The newer TP materials are generally more costly than current epoxies and bismaleimides are. The extensive use of composites will be tempered by costs and tradeoffs between cost and performance. Inasmuch as the total characterization of the performances of these promising "new improved" composite matrices (toughened thermosets as well as TP's) is incomplete and new, it is expected that untried materials will be introduced with caution.

This work was done by Norman J. Johnston and Paul M. Hergenrother of **Langley Research Center**. *Further information may be found in NASA TM-89104 [N87-20390], "High Performance Thermoplastics: A Review of Neat Resin and Composite Properties."*

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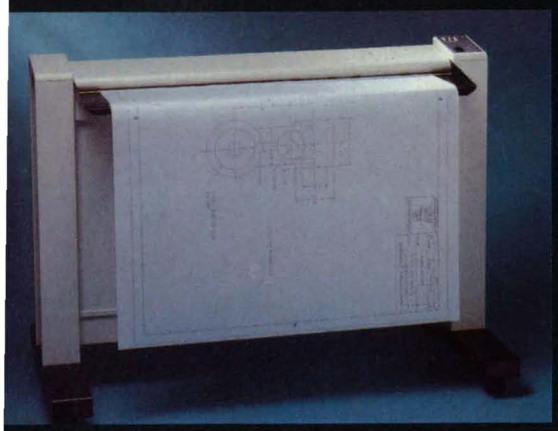

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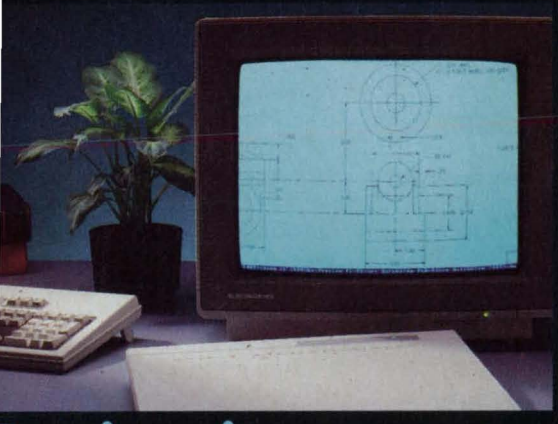

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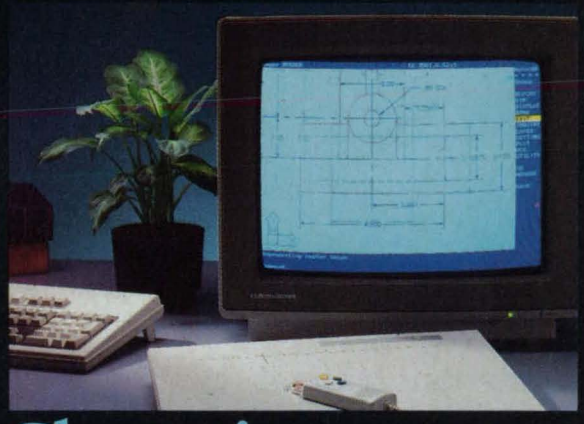

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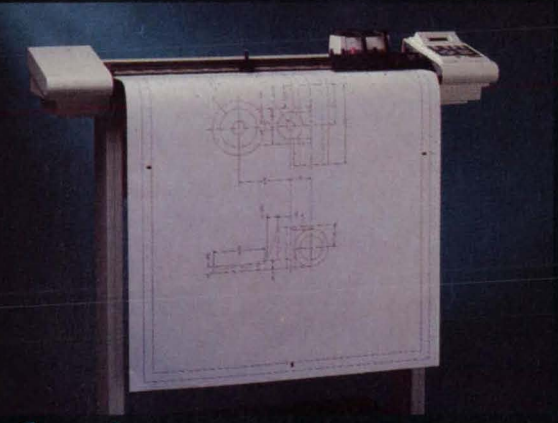

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Electronic Systems

Numerical Arc-Segmentation Algorithm for a Radio Conference

NASARC helps administrations allocate geostationary fixed satellite services.

The NASARC computer program was developed from the general planning principles and decisions of both sessions of the World Administrative Radio Conference on the Use of the Geostationary Satellite Orbit and on the Planning of Space Services Utilizing It (WARC-85 and WARC-88). NASARC was written to help countries satisfy requirements for nationwide fixed-satellite services from at least one orbital position within a predetermined arc.

Each of the predetermined arcs generated by NASARC is based on a common arc segment visible to a group of compatible service areas and provides a means of generating a highly flexible allotment plan with a reduced need for coordination among administrations. The selection of particular groupings of service areas and their associated predetermined arcs is made according to a heuristic approach, using several figures of merit designed to confront the most difficult allotment problems. NASARC attempts to select groupings and sizes of predetermined arcs so that the requirements of all administrations are met before the available orbital arc is exhausted. The predetermined arcs allow considerable freedom of choice in the positioning of space stations for all members of any grouping.

The approach to planning allotments for which NASARC was designed involves two phases. In the first phase, NASARC is used to identify predetermined arc segments common to groups of administrations. Those administrations within a group and sharing a common predetermined arc segment would be able to position their individual space stations at any one of a number of orbital positions within the predetermined arc. In the second phase, a plan-synthesizing program (such as the ORBIT program resident at the International Frequency Registration Board in Geneva, Switzerland) is used to identify example scenarios of specific placements of space stations.

NASARC software is modular and consists of several programs to be run in sequence. The grouping module, NASARC1, identifies compatible groups of several service areas that are sufficiently separated geographically so that colocation or near colocation of their space stations will permit the satisfaction of a downlink-performance criterion specified by the user. Pairwise compatibility between systems is assessed on the basis of the separation between satellites required to meet this criterion.

NASARC2 examines all groups of compatible administrations with their corresponding arc segments and computes a common predetermined arc. After an orbital slot of sufficient size has been found, NASARC2 calculates the required orbital separation between the critical group and its potential east and west neighbors and determines the placement of the predetermined arc accordingly.

NASARC3 updates and extends the feasible orbital locations for predetermined arcs associated with compatible groups of service areas to provide flexibility for rearrangement if necessary. NASARC4 performs rearrangement of predetermined arc segments where rearrangement will provide increased total arc available for subsequent placement of additional predeter-

mined arcs and produces the final report of the NASARC software package.

In addition to planning assumed homogeneous systems, NASARC can take into account such factors as attenuation by rain, parameters of individual antennas, options for calculations of powers, minimum-power values, different required carrier-to-interface ratios, variable grouping criteria, and affiliated sets of service areas. The modules allow the modification of baseline assumptions, including some as they pertain to individual service areas. NASARC array dimensions have been structured to fit within the currently available 12-MB memory capacity of the International Frequency Registration Board computer facility.

NASARC was written in ANSI standard FORTRAN 77 and developed on an AMDAHL 5860 computer running under the IBM VM operating system. The package requires 8.1 MB of central memory. NASARC (version 4.0) was written in 1988.

IBM and VM are registered trademarks of International Business Machines. AMDAHL 5860 is a trademark of Amdahl Corp.

This program was written by W. A. Whyte, Denise S. Ponchak, A. O. Heyward, John E. Zuzek, and R. L. Spence of **Lewis Research Center**. *For further information, Circle 130 on the TSP Request Card.*
LEW-14815

Machinery

Computing Thermal Performances of Shafts and Bearings

A general, modular program is applicable to realistically complicated systems.

The SHABERTH computer program was developed to predict the steady-state and transient thermal performance of a multibearing shaft system operating with either wet or dry friction. SHABERTH calculates the loads, torques, temperatures, and fatigue lives for ball and/or roller bearings on a single shaft. The comprehensive nature of this program enables the study of many causes of instabilities in bearings. The program also provides for analysis of the reaction of the system to the termination of the supply of lubricant to the bearings and other lubricated mechanical elements. SHABERTH should prove to be a valuable software tool in the design and analysis of shaft bearing systems.

The SHABERTH program is structured with four nested calculation schemes. The thermal scheme calculates steady-state and transient temperatures for a given operating state. The bearing-dimensional-equilibrium scheme uses (1) the bearing temperatures predicted by the temperature-mapping subprograms and (2) the distributions of loads on rolling-element raceways, predicted by the bearing subprogram, to calculate diametral clearance of a bearing for a given operating state. The shaft-bearing-system-load-equilibrium scheme calculates the position of the inner rings of bearings relative to the respective outer rings such that a portion of the external loading applied to the shaft is brought into equilibrium by the loads that develop on the rolling elements at the inner ring of each bearing for a given operating state. The bearing rolling-element-and-cage-load-equilibrium scheme calculates the equilibrium positions and rotational speeds of the rolling elements and cages on the basis of the relative positions of inner and outer rings, the effects of inertia, and friction conditions.

The ball-bearing subprograms in the current SHABERTH program include an elastohydrodynamic (EHD) film-thickness model that accounts for heating in the contact area and lubricant-film starvation; a new model for traction combined with an asperity-load-sharing model; a model for the hy-

drodynamic rolling and shear forces in the inlet zone of lubricated contacts, which model accounts for the degree of lubricant-film starvation; a model for normal and friction forces between a ball and a cage pocket, which model accounts for the transition between the hydrodynamic and elastohydrodynamic regimes of lubrication; and a model of the effect, on fatigue life, of the ratio of the EHD plateau film thickness to the composite surface roughness.

SHABERTH is intended to be as general as possible. The models in SHABERTH provide for the complete mathematical simulation of real physical systems. A system is limited to a maximum of 5 bearings supporting the shaft, a maximum of 30 rolling elements per bearing, and a maximum of 100 temperature nodes. The SHABERTH program is modular and has been designed to permit refinement and replacement of various component mathematical models as the need and opportunities develop.

SHABERTH is available by license for a period of 10 years to approved licensees. The licensed program product includes the source code and one copy of the supporting documentation. Additional copies of the documentation may be purchased separately at any time.

The program is written in FORTRAN IV and has been implemented on both a UNIVAC 1100-series computer and a CRAY X-MP running a UNICOS 5.1 operating system. The UNIVAC version has a central-memory requirement of approximately 86K of 36-bit words, and the CRAY X-MP version has a memory requirement of 162K of 64-bit words. The UNIVAC version of SHABERTH was developed in 1976, and the CRAY version was updated in 1982. The CRAY version is the same as before, except that it contains two more lubricants — a low-temperature special E1 and now a low-viscosity fuel, RP-1.

This program was written by Claudia M. Woods of **Lewis Research Center**. *For further information, Circle 136 on the TSP Request Card.*
LEW-14860

Updated SINDA'85/FLUINT

Fluid and thermal systems governed by diffusion-type equations are analyzed via lumped-parameter models.

SINDA, the Systems Improved Numerical Differencing Analyzer, is a software system for solving lumped-parameter representations of physical problems governed by diffusion-type equations. Although SINDA was originally designed for the analysis of thermal systems represented in electrical analog, lumped-parameter form, its use can be extended to include other classes of physical systems that can be mathematically modeled in this form.

As a thermal-analysis program, SINDA can represent such interrelated phenomena as sublimation, diffuse radiation within enclosures, and transport delay effects, and can perform sensitivity analysis. FLUINT, the FLUid INTegrator, is an advanced one-dimensional fluid-analysis program that solves the equations of arbitrary fluid-flow networks. The working fluids can be single-phase vapors, single-phase liquids, or two-phase fluids. The SINDA'85/FLUINT system enables the analysis of the mutual influences of thermal and fluid aspects of physical systems.

The SINDA software system consists of a programming language, a preprocessor, and a subroutine library. The SINDA language is designed for working with lumped-parameter representations and finite-difference solution techniques. The preprocessor accepts programs written in the SINDA language and converts them into standard FORTRAN. The SINDA library consists of a large number of FORTRAN subroutines that perform a variety of commonly needed actions. The use of these subroutines can greatly reduce the programming effort required to solve many problems.

A complete run of a SINDA'85/FLUINT model is a four-step process. First, the

user's desired mathematical model is run through the preprocessor, which writes out data files for a processing program to read and translates the user's program code. Then the translated code is compiled. The third step requires linking of the user's code with a library of parts of a processing program. Finally, the processing program is executed.

The features of the SINDA'85/FLUINT program include 20,000 nodes, 100,000 conductors, 100 thermal submodels, 10 fluid submodels, two-phase flow, capillary devices, fluids defined by the user, gravitational and accelerational body forces on a fluid, and variable volumes. SINDA'85/FLUINT offers two finite-difference numerical solution techniques: an explicit formulation via the forward-difference explicit approximation, and an implicit formulation via the Crank–Nicolson approximation.

The program enables the simulation of nonuniform heating and facilitates mathematical modeling of thin-walled heat exchangers. The ability to model nonequilibrium behavior within two-phase volumes is included. Recent improvements were made in those parts of the program that mathematically model evaporator pumps and other capillary-assist evaporators.

SINDA'85/FLUINT is available by license for a period of 10 years to approved licensees. The licensed program product includes the source code and one copy of the supporting documentation. Additional copies of the documentation may be purchased separately at any time.

SINDA'85/FLUINT is written in FORTRAN. Version 2.3 has been implemented on a DEC VAX-series computer operating under VMS and on Sun-3 and Sun-4 computers operating under SunOS. Binaries are included for the Sun computers. The versions for both computers contain a graphical-display program called EXPLOT. The VAX version of EXPLOT requires the DISSPLA graphics package, while the Sun version requires TEMPLATE. The VAX version also contains SINGE, an additional program developed at Johnson Space Center for graphical representation of data. The CONVEX version is a part of the 1988 version (version 2.2). SINDA was developed in 1971, and fluid capability was first added in 1975. SINDA'85/FLUINT version 2.3 was released in 1990.

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This program was written by Brent Cullimore and Steve Ring of Martin Marietta Corp. for **Johnson Space Center**. *For further information, Circle 69 on the TSP Request Card.*
MSC-21774

Mechanics

Hardware, Techniques, and Processes

Books and Reports

Autonomous Frequency-Domain Identification

A test and data-processing system determines plant models and uncertainties.

NASA's Jet Propulsion Laboratory, Pasadena, California

An integrated system of methods, digital signal-processing, and algorithms identifies the parametric model of large, flexible structures. The experiments in the development of this system have been conducted on a laboratory model (see figure) that is intended to represent a large space antenna or flexible spacecraft. This capability is also applicable to many terrestrial systems, especially to the robust control of dynamic plants and processes, robust control of systems about which knowledge is uncertain or incomplete, decentralized control systems, and knowledge-based control systems.

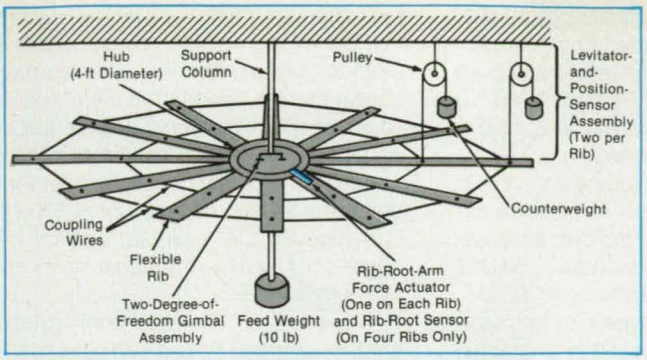
Making efficient use of excitation inputs from a limited number of actuators and outputs from a limited number of sensors on the structure, the system operates automatically on line (on orbit in the spacecraft application) to obtain the information necessary to adjust a control system to the uncertain and/or evolving dynamics of the structure. This information includes the transfer functions of the controlled structure and the identification of a set of mathematical models that represent the structure with acceptable accuracy. The identification methodology incorporates an output error characterization, based on the additive uncertainty in the mathematical model of the plant. This characterization has been used for the analysis and synthesis of robust control systems.

Data on the dynamics of the structure are obtained by measuring its responses to stochastic, impulse, sinusoidal, and/or other excitations. Spectral responses are estimated from these data. Then a para-

metric mathematical model of the structure is obtained by a process of curve-fitting the estimated spectra to a rational transfer function. The order of the model is then estimated in two stages: first, an initial estimate of the order is obtained by use of a product-moment-matrix test; second, the optimal order in the vicinity of this estimate is found by making a sequence of curve fits with varying orders. The optimal order is judged by comparing the qualities of the output-error profiles for each curve fit. The uncertainty bounds needed for on-line robust control tuning are estimated by use of the cross-spectral analysis of the output error.

The results of experiments on the antenna model show that the curve-fitting algorithm produces the reduced-order mathematical model that minimizes the additive uncertainty. The nominal estimated transfer function and the estimate of the additive uncertainty then become available for use in optimization of the control algorithm for robust performance and stability.

This work was done by Edward Mettler, Yeung Yam, David S. Bayard, Fred Y. Hadaegh, Mark H. Milman, and Robert E. Scheid of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 129 on the TSP Request Card.*
NPO-18099



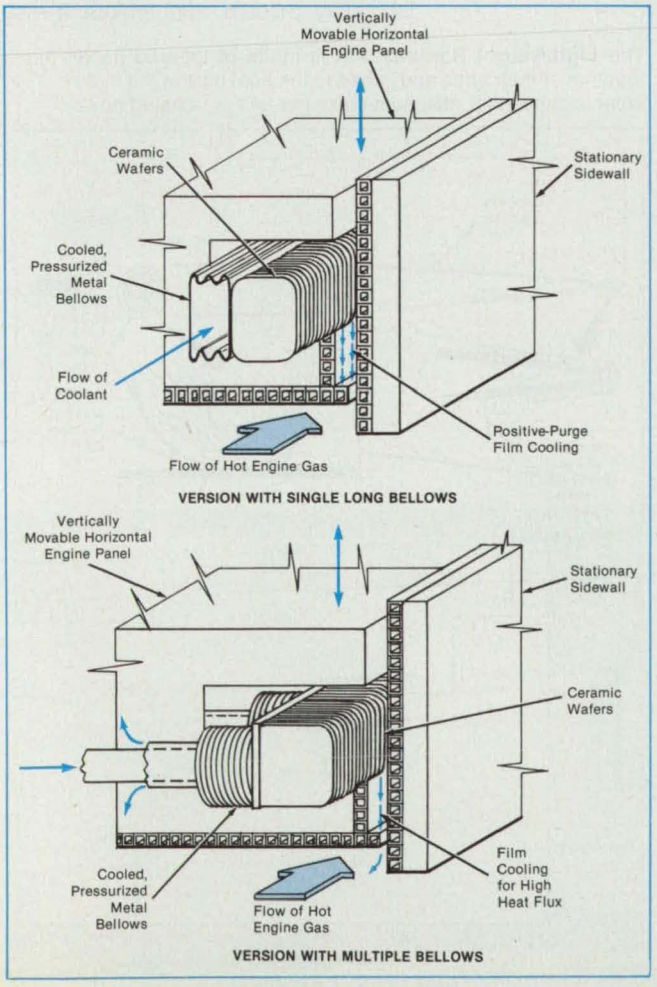
This **Antenna Structure** has been used in experiments to develop the autonomous identification system. (Different versions of this illustration have been presented in prior articles of *NASA Tech Briefs* about parts of the system.)

Dynamic, High-Temperature, Flexible Seals

Stacks of ceramic wafers conform to sealed surfaces.

Lewis Research Center, Cleveland, Ohio

Dynamic, flexible ceramic seals are being developed for use at high temperatures in high-performance, variable-geometry, hypersonic airplane engines. The seals are needed to block the flows of hot engine flow-path gases through the gaps between movable engine panels and adjacent stationary engine sidewalls. Pressures and thermal loads on the relatively compliant sidewalls can widen the gaps to as much as 0.15 in. (6.4 mm), thereby giving rise to the need for very compliant seals to conform to distortions and keep the gaps plugged. Seals of the new type could also be used in hypersonic engines, two-dimensional convergent/divergent and vectored-thrust exhaust nozzles, the airframes of reentry vehicles, the casings of rocket



Stacked Ceramic Wafers are pressed against the stationary sidewall by pressure in one or more metal bellows.

motors, furnaces, and other applications.

The seals are expected to prevent engine flow-path gases with temperatures as high as 1,200 to 5,000 °F (650 to 2,760 °C) and pressures as high as 100 psi (0.7 MPa) from leaking past the engine panels to back engine cavities, where they could cause losses of engines or of entire airplanes. The seals must perform successfully at heat fluxes greater than 1,100 Btu/ft^2•s (11.4 MW/m^2) in supersonic flows.

A seal of the new type can be made of ceramic wafers stacked in a channel along the edge of a movable engine panel. The seal conforms to the large distortions of the movable and/or the stationary sidewall by relative sliding between adjacent wafers. Various techniques can be used to preload the ceramic wafers transversely against the stationary sidewall. In each of the two versions illustrated in the figure, an actively cooled, pressurized metal bellows performs this function.

The wafers can be made of any of the high-strength, tough, engineered ceramics, like silicon carbide, silicon nitride, or aluminum oxide. Analytical studies have shown that for the extreme thermal environment of a hypersonic engine, silicon carbide is the leading candidate. Silicon carbide can operate continuously at temperatures as high as 2,500 °F (1,370 °C) and requires the minimum coolant because of its high thermal conductivity and high emissivity.

Two methods of active cooling have been investigated for use with seals of this type in operation at heat fluxes above 300 Btu/ft^2•s (3.3 MW/m^2). The first is to purge the seal positively from the engine cavity behind the movable panel. The second is to purge the seal positively from the cavity behind the wafers. A coolant gas like helium is efficient because of its high heat capacity and low density. Also, because helium is chemically inert, the positive purge flow into the flow chamber of the engine can prevent the potentially explosive hydrogen/oxygen mixture that would be used in such an engine from leaking behind the seal.

This work was done by Bruce M. Steinetz of **Lewis Research Center** *and Paul J. Sirocky of Sverdrup Technologies, Inc. Further information may be found in NASA TM-103737 [N91-22567], "High Temperature Performance Evaluation of a Hypersonic Engine Ceramic Wafer Seal."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

This invention has been patented by NASA (U.S. Patent No. 4,917,302). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center [see page 20]. Refer to LEW-14695.

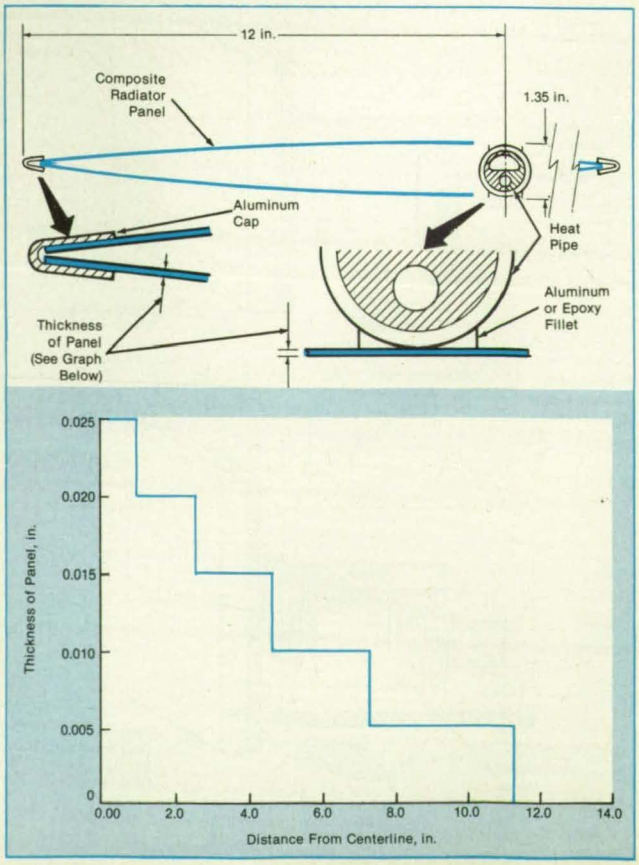
Lightweight Radiator Fin

The mass necessary to radiate a given amount of power would be minimized.

Lyndon B. Johnson Space Center, Houston, Texas

A fin designed to radiate heat from a heat pipe into a surrounding vacuum is optimized with respect to mass; that is, given the type of material used to construct the fin, the mass per unit radiated power is minimized. Although the fin is intended primarily for use as part of the cooling system of a space station, it could also be used on Earth to cool equipment in a laboratory vacuum. Furthermore, it may

The **Lightweight Radiator Fin** is made of tapered panels bent together at their ends and joined to the heat pipe in the middle. The taper is chosen for minimum mass per unit of radiated power.



be possible to modify the basic design equations to design minimum-mass fins for cooling by conduction or convection.

The design is based in part on a postulate, advanced in 1960, that to obtain minimum mass, one must provide for a constant negative gradient of temperature from the root (the end of the fin in contact with the heat pipe) to the tip. To obtain a constant gradient of temperature, it is necessary to make the thickness of the fin decrease nonlinearly with distance from the root to the tip, according to a function derived from the law of thermal radiation.

The prototype fin for the original application is made of aluminum/graphite-fiber composite. Each layer of the composite is 0.005 in. (0.127 mm) thick. Two panels of the composite material, each 24 in. (61 cm) wide, are attached to opposite sides of the heat pipe, then bent together and joined at the tips by aluminum caps (see figure). Each panel is five layers thick at the middle, where it makes contact with the heat pipe. To provide an approximation to the required taper, each succeeding layer of each panel is shorter than the layer before it. The first layer extends out to 11.3 in. (28.7 cm) from the middle, the second layer to 7.2 in. (18.3 cm), the third to 4.6 in. (11.7 cm), the fourth to 2.5 in. (6.4 cm), and the fifth to 0.9 in (2.3 cm). An outer coat of aluminum smooths out the stair-step shape of the cascaded layers. Preliminary measurements show that the heat-transfer characteristics of the stepped design are similar to those of the ideal continuous-taper design.

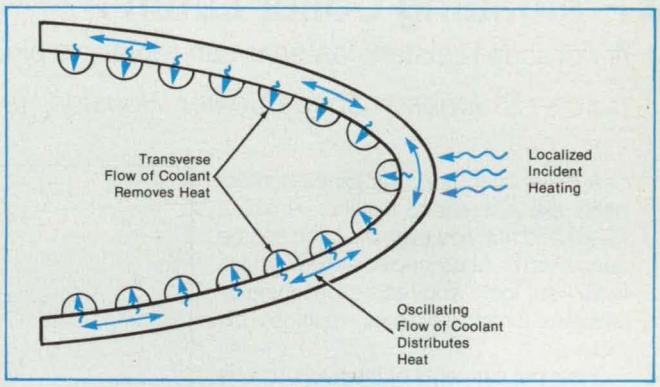
This work was done by W. Russ Long, III and Eugene K. Ungar of **Johnson Space Center**. *For further information, Circle 47 on the TSP Request Card.* *MSC-21558*

Oscillating-Coolant Heat Exchanger

These devices might be useful in situations in which heat pipes are inadequate.

Langley Research Center, Hampton, Virginia

It has recently become necessary to design cooled structures that can survive extremely large heat fluxes. As an example of this requirement, the leading edge of the cowl of a scramjet engine can be subjected to shock-interference heating, which can produce heat fluxes with magnitudes of the order of 60,000 Btu/ft^2-s (680 MW/m^2). The conceptual oscillating-coolant heat exchanger (OCHEX) may be able to endure this extreme heat flux and may have a multitude of other applications.



An **Oscillating-Coolant Heat Exchanger** on a leading edge of an aircraft would survive and carry away intense local heat flux.

In its primary intended use, the OCHEX would efficiently transport heat from its hotter portions to its cooler portions, in this sense acting as a classical heat pipe. However, unlike in a heat pipe, the heat would be transported by oscillation of a single-phase fluid, called the primary coolant, in coolant passages. There would be no time-averaged flow in the tubes, so that either the heat would be removed from end reservoirs on every cycle or the heat would be removed indirectly by cooling the sides of channels with another coolant.

The figure schematically illustrates an OCHEX on a leading edge of an aircraft. Both OCHEX devices and conventional heat pipes operate as essentially isothermal devices. The advantage an OCHEX has over a heat pipe is that the OCHEX is not limited by the fluid-dynamic heat-transport constraints on the capillary pumping of liquid and the flow of vapor. In addition, the boiling limit on liquids in OCHEX devices is not as severe as in heat pipes. Because a heat pipe operates near its saturation temperature, the drop in temperature through the liquid in its wick represents superheating, which can cause boiling. The temperature of the fluid in an OCHEX device is not constrained to the saturation temperature; consequently, one can choose from among a much greater variety of primary coolants for various operating conditions. A disadvantage of an OCHEX device is that it requires external

power and possibly control to force the oscillating flow.

The oscillating flow produces a velocity boundary layer, the thickness of which is proportional to the square root of the ratio of the kinematic viscosity to the circular frequency of the oscillation. At higher frequencies, this flow attains a nearly constant velocity profile in the crosswise direction (a "slug" flow) with thin velocity boundary layers at the walls of the coolant passages. The slug of fluid in the middle of each passage accepts heat from the side walls through the velocity boundary layer by normal molecular conduction, convects this heat along the channel to a region of lower temperature, and releases this heat to the side walls, or reservoir, before returning to start a new cycle. The net effect of this behavior is a highly effective streamwise transfer of energy, which makes the operation nearly isothermal, as in a heat pipe.

One feature of the OCHEX is that there is a net flux of heat through the conductive primary coolant passage walls somewhere in the device. Also, there is an oscillating flow of the primary coolant in the primary coolant passages with a displacement amplitude that can range from that of an acoustic disturbance to a length greater than that of the coolant passages.

Conceptual OCHEX devices include leading-edge cooling devices in hypersonic aircraft and "frost-free" heat exchangers. The OCHEX concept can be used in almost any situation in which a heat pipe can be used and in other situations in which heat pipes may not be usable.

This work was done by Stephen J. Scotti, Max L. Blosser, and Charles J. Camarda of **Langley Research Center**. *For further information, Circle 151 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14033.

Preloading Collet Latch

A vibration-resistant fastener can replace a pinned or threaded fastener.

Lyndon B. Johnson Space Center, Houston, Texas

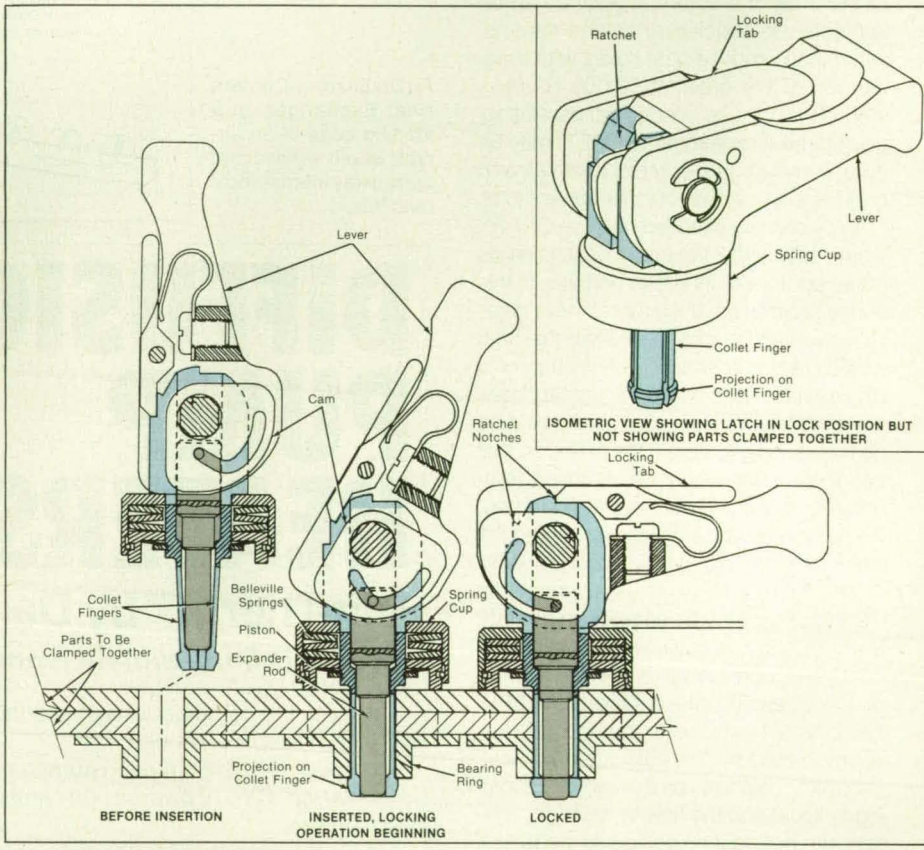
A collet latch preloads joined components like a threaded fastener. Unlike a screw and nut, however, the latch can be connected or disconnected almost instantly, without tools, and resists loosening by vibration. It can also directly replace a pin fastener.

Principal elements of the latch include a slotted collet, a preloading spring assembly, and an actuating lever (see figure). The latch is inserted in a hole in the parts to be clamped together while in its unclamped configuration, with the actuating lever up. In this configuration, an internal expander rod is in its uppermost position so that the collet fingers are sprung radially inward. The collet thus fits readily in the fastener hole.

Once the collet is seated in the hole, the user rotates the lever clockwise. This action moves the expander rod downward, forcing the collet fingers outward. Projections on the tips of the collet fingers engage a bearing ring on the far side of the hole.

Continued rotation of the lever forces a cam surface against a cup that holds the preloading spring assembly. The cup compresses a set of Belleville springs in the assembly against a piston, which in turn presses against the upper surface of the upper part to be fastened. When the lever has been rotated a full 90° clockwise, a locking tab engages a ratchet notch. A curved spring holds the locking tab in the notch. In this configuration, the latch is secure.

To disconnect the latch, the user simply presses down on the locking tab with a finger while rotating the lever counterclockwise. A full 90° rotation retracts the expander rod. The collet fingers once again spring inward, and the collet can be extracted from the hole.



Cross Sections Show the Sequence of locking operations. When the mechanism is fully locked, the actuating lever is 90° from its starting position and held by a locking tab engaged in a ratchet notch.

This work was done by Clarence J. Wesselski and Kornel Nagy of **Johnson Space Center**. *For further information, Circle 56 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 20]. Refer to MSC-21730.

Cable Feedthrough Between Liquid Oxygen and Ambient

Encapsulant and back pressure provide double protection.

Lyndon B. Johnson Space Center, Houston, Texas

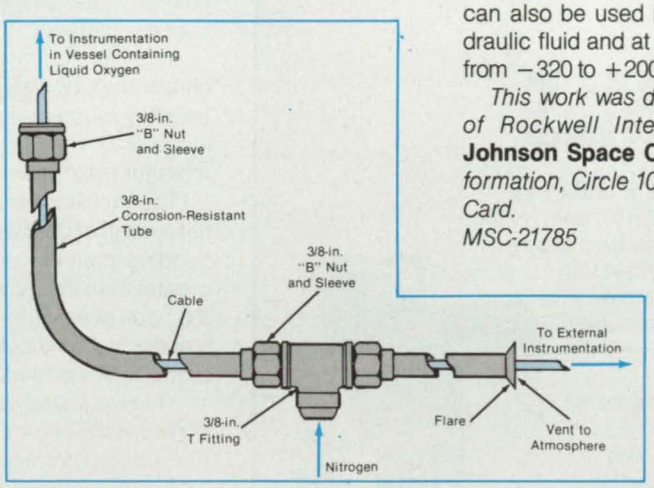
A cable-feedthrough tube between the ambient air and the interior of a vessel containing liquid oxygen protects the external instrumentation and the cable from the oxygen. The cable in the tube is surrounded by a potting compound. In addition, the tube provides a flow of gaseous nitrogen to dilute the oxidant and make it harmless in case of leakage through a crack in the potting compound.

The feedthrough consists of two tube sections joined by a T-fitting (see figure). To begin the assembly of the feedthrough, one slips a tube section with a 90° bend over the cable. Potting compound is injected into this section as it is heated from the outside by a heat gun to enable the compound to flow readily. Injection is stopped when the flowing compound appears at the opposite end. One end of this section is fastened with a nut and sleeve to the vessel that is to contain liquid oxygen; the opposite end is attached with a nut and sleeve to a T-fitting. Unlike the tube, the T-fitting is not filled with the potting compound.

A straight tube section is slid over the remaining exposed part of the cable and filled with the potting compound. One end is bolted to the T-fitting; the outer end is flared and vented to the atmosphere. Finally, the middle port of the T-fitting is connected to a supply of gaseous nitrogen.

The feedthrough has been used in liquid oxygen flows of 18,000 gal/min (1.1 m^3/s) at a pressure of 150 $lb/in.^2$ (1.03 MPa) and temperatures of −297 °F (−183 °C). It can also be used in such liquids as hydraulic fluid and at temperatures ranging from −320 to +200 °F (−196 to +93 °C).

This work was done by Don A. Myers of Rockwell International Corp. for **Johnson Space Center**. *For further information, Circle 104 on the TSP Request Card.*
MSC-21785



Two Tube Sections joined by a T-fitting enclose an instrumentation cable.

Stiffer Circumferential Dovetail Mount for Turbine Blades

Material is distributed to resist bending more efficiently.

Marshall Space Flight Center, Alabama

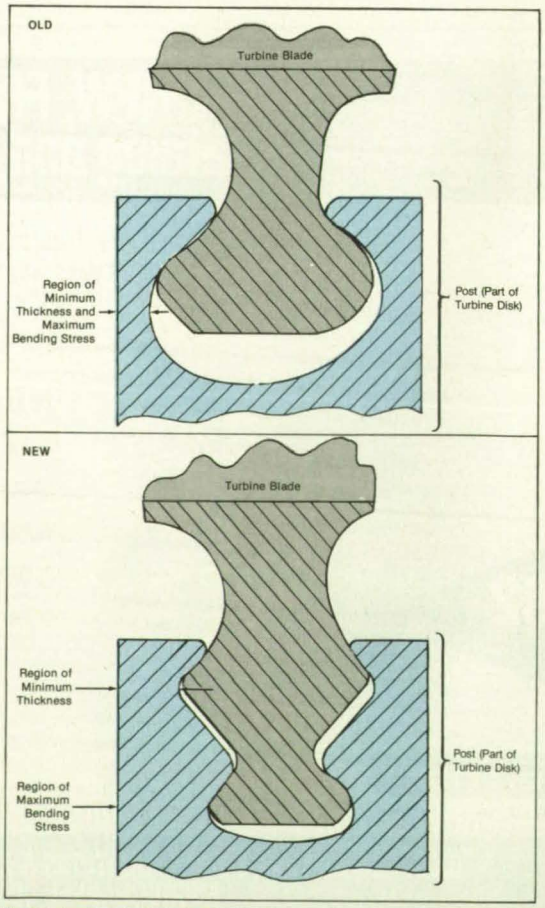
A multihook circumferential dovetail configuration for mounting blades around the circumference of a rotor disk in a turbomachine reduces the bending stresses in the disk. In the multihook dovetail configuration, the posts (which are those subparts of the circumferential part of the disk that remain after machining of the dovetail slots) are relatively thick at the location of the maximum bending moment.

In a conventional circumferential dovetail, the location of minimum thickness of a post is near the point where maximum bending moment is applied, and a substantial amount of post material is remote from that point and adds to the bending moment (see figure).

The multihook configuration, in contrast, provides a substantial section of post where it is most needed to resist the maximum bending moment near the lower hook. The thickness here is greater than that at the upper hook and much greater than that at the hook of a single-hook dovetail. Moreover, the amount of post material that contributes to the overturning moment is less than in the single-hook configuration.

This work was done by Steven D. Ward and Martin J. Pierce of General Electric Company for **Marshall Space Flight Center.** *For further information, Circle 134 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28543.



The **Multiple-Hook Dovetail Configuration** distributes material more efficiently (with respect to the ability of the posts to resist overturning moments) than does the single-hook dovetail configuration.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Computed Turbulent Free Shear Flow of Air

The standard k–ϵ model of turbulence yields fairly accurate results.

A symposium paper discusses the numerical simulation of a turbulent free shear flow of a nonreacting compressible fluid. This is one of several types of flow that occur in ramjets; the ability to compute such flows could be essential to advances in design. No currently available mathematical model of turbulence is adequate to compute the behavior of a free shear layer under all flow conditions expected to occur in practice.

This study involves the k–ϵ model — a two-equation turbulence model in which the eddy viscosity, μ_t, governs the diffusive spread of the kinetic-energy, k. Several versions of this model, some excluding and some including corrections for the effects of compressibility, — have been found to predict more mixing in single stream free shear layers than is observed.

The flow investigated here is one for which ample experimental data are available: the nearly-two-dimensional supersonic flow of air from a plenum along a channel 36 in. (91.4 cm) long, 2 in. (5.1 cm) high, and 6 in. (15.2 cm) wide. One stream enters the upper half of the channel at mach 1.25, separated by a splitter plate at the inlet from another stream that enters the lower half at mach 3.06. The free shear layer in question is the mixing layer at midheight between these two streams.

This flow was computed via the two-dimensional time-dependent, mass-weighted, Reynolds-averaged Navier–Stokes equations. These equations were solved numerically by a finite-volume computer program that can operate in an implicit or explicit mode (depending on the time step selected) and is accurate to second order in space. The computational grid was uniformly spaced in the streamwise direction and variably spaced across the flow. The standard k–ϵ model was incorporated into the computer program.

The isomach lines, profiles of streamwise velocity, and profiles of turbulent kinetic energy that result from the computation are plotted. The computed distributions of pressure on the upper and lower surfaces of the channel and profiles of mean streamwise velocity are also plotted and compared with experimental values. The computed and experimental flows were found to be in fair agreement. The rate of spread of the computed free shear layer (based on the maximum velocity slope) was found to be about ⅔ the rate of spread of the experimental free shear layer. This behavior, while opposite in behavior to the case of a single stream, is in general agreement with other observations of two-stream shear flows under similar flow conditions.

This work was done by J. R. Viegas and M. W. Rubesin of **Ames Research Center**. *To obtain a copy of the report, "Turbulence Modeling of Compressible Free Shear Flows," Circle 8 on the TSP Request Card.*
ARC-12662

Computer-Graphical Visualization of Flow Fields

Recent and anticipated developments are reported.

A report discusses the state of the art of visualization of flow fields by means of computer graphics. It describes recent trends, problems, and limitations of current equipment and computer programs in general and then focuses on the approach used at Ames Research Center to create the visual displays.

The techniques used to date operate on computer simulations of flows to create scenes that represent the three-dimensional dynamic flow fields. Popular types of visualization include paths of particles entrained in the flow field, contours or transparent surfaces of constant magnitude of pressure or another scalar quantity, and arrow/vector representations of velocity. False colors, sound, or other cues can also add understanding of flow fields.

To enhance the perception of three-dimensionality in the two-dimensional images, it has been found important to use equipment and computer programs that enable the viewer to alter the perspective. The rotation of the flow field or of the viewer about the flow field was found to be one of the best cues of this kind. Other cues include the representation of solid bodies with hidden surfaces removed and synthetic surface shading. Stereoscopy has also been used, but its effectiveness varies from person to person.

Although the motion in a scene need not be on a real-time scale, it should be rapid and smooth enough to impart an understanding of dynamical features of the flow. For this purpose, the system should produce at least 10 frames per second. The approach used at Ames Research Center has been to use computer-graphics work stations built for high performance in the conversion of the three-dimensional com-

puter-generated scenes into screen displays and to augment those work stations with video-tape and 16-mm-film recording equipment. Scenes of moderate complexity (for example, tracer particles moving with the flow around a cylinder) can be displayed rapidly enough on the workstation screen to enable the dynamics to be understood. In complicated flow fields (for example, flows around aircraft), for which it can take many seconds to generate each frame, the screen displays are recorded on video tape or 16-mm film for subsequent playback at higher frame rates.

The factor that limits the frame rate in current work stations is the speed for creating representations of solid bodies; in particular, the removal of hidden surfaces by use of a "Z-buffer." Decreased shading time is also required. It will probably take several years before work stations priced below $100,000 (1987 dollars) will be fast enough for adequate studies of flow about complicated solid bodies.

This work was done by Val Watson, Pieter Buning, and Diana Choi of **Ames Research Center** *and Gordon Bancroft, Fergus Merritt, and Stuart Rogers of Sterling Software. Further information may be found in "Use of Computer Graphics for Visualization of Flow Fields."*

Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500.
ARC-12150

Computed and Measured Flow in a Turnaround Duct

Measurements indicate deficiency in a mathematical model of turbulence.

A report presents a theoretical and experimental study of the subsonic flow of air in a 180°-turnaround duct of a rectangular cross section. The purpose of this study was to conduct a partial simulation of conditions similar to (but not as complicated as) those in the axisymmetric duct of the Space Shuttle main engine. This is part of a continuing effort to develop the capability to simulate complicated turbulent internal flows with large curvatures like those in rocket engines and turbomachinery.

The duct had a gap between the inner and outer walls of 3.81 cm and a width of 38 cm along its entire length. The axis of the bend was parallel to the width. The inner radius of the bend was 1.91 cm. The duct was operated as part of a wind tunnel with a mean mach number of 0.1. Tests were conducted at total pressures of 1.2 and 12 atm (0.122 and 1.22 MPa) to obtain Reynolds numbers (based on the

3.81-cm gap) of 10^5 and 10^6, respectively. The side (3.8-cm-high) walls were made of transparent plastic to give optical access. Inner windows incorporated suction slots to remove the side-wall boundary layers to keep the flow as nearly two-dimensional as possible. The spatial distributions of mean and turbulent components of velocity were measured with a forward-scattering, two-color laser doppler velocimeter, but only the mean velocities are discussed in the report. Static pressures were measured by a system of electronically scanned pressure transducers.

The flow was simulated by use of the INS3D computer code, which numerically integrates the Navier–Stokes equations of incompressible flow. The effects of turbulence were simulated by a Prandtl-mixing-length algebraic model of turbulent viscosity. This simulation was a "blind test" for both the computer code and the algebraic model of turbulence, in that it was performed without knowledge of any of the flow measurements other than the upstream boundary conditions. There was no "tuning" of the model, the numerical-dissipation parameters used to stabilize the numerical-integration scheme in the computer code, the viscosity terms, or the grid distribution to match the experimental data.

The authors draw several conclusions from a comparison of the computed and measured flows. These conclusions can be summarized as follows:

1. The mean flow is well predicted over the first half of the bend, since the flow field is mainly driven by the pressure field.
2. In the second half of the bend and downstream, the boundary layers on most surfaces are thinner than the computed ones. Apparently, the experimental mixing lengths near the walls are larger than those of the model.
3. The measured drop in static pressure through the bend is larger than the computed pressure drop. This result implies that the skin friction is larger than assumed in the computation and is consistent with thinner measured boundary layers.
4. Separation occurs on the inner wall near the end of the bend, and its size and extent increase with increased Reynolds number, although the point of separation remains unchanged. The computation shows the opposite trend with Reynolds number, predicting about the right amount of separation at the lower Reynolds number but almost none at the higher one. The separation bubble is unsteady and unstable, causing large velocity fluctuations in the flow that persist far downstream.
5. Measured velocity profiles downstream of the bend retain "plug flow"-type shapes, whereas the computation predicts an approach toward fully developed channel-flow profiles.
6. The mixing-length model of turbulence fails to predict many of the important features of the flow accurately. To obtain accurate solutions it may be necessary to solve the time-dependent three-dimensional Navier–Stokes equations and/or use turbulence models of higher order.
7. Although time-resolved pressure measurements were not made, the unsteady nature of the flow in the separation region implies unsteady pressures on the walls. Because fluctuations in pressure can cause damage, it is important to develop reliable and accurate means of predicting not only the occurrence of separation and the correct trend with Reynolds number but also the changes in the shape of the duct necessary to eliminate such separation.

This work was done by Daryl J. Monson and H. Lee Seegmiller of **Ames Research Center** *and Paul K. McConnaughey of Marshall Space Flight Center. Further information may be found in AIAA paper 89A-25232, "Comparison of LDV Measurements and Navier–Stokes Solutions in a Two-Dimensional 180-Degree Turn-Around Duct."*

Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500. ARC-12614

Machinery

Hardware, Techniques, and Processes

Books and Reports

Computer Programs

Liquid/Gas Separator Handles Varying Loads

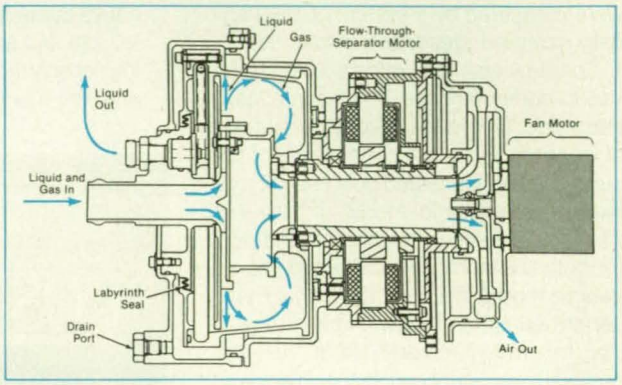
A two-motor design enhances adjustability.

Lyndon B. Johnson Space Center, Houston, Texas

A liquid/gas separator includes two independent motors — one for pumping the mixture and the other for drawing off the extracted gas. The two materials can thus be moved at the speeds best suited for them.

The unit was developed to separate air from urine in a spacecraft wastewater-treatment system. Presumably, it could also function in normal gravity. It is made largely of titanium to resist corrosion.

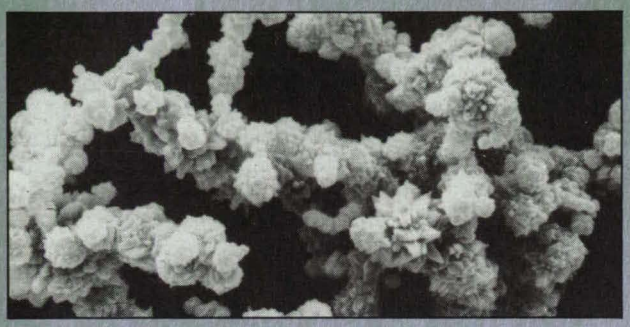
A flow-through "pancake"-style brushless dc motor drives the separator rotor at the appropriate speed to separate the liquid from the gas (see figure). Downstream, another brushless dc motor drives a fan efficiently at a higher speed to remove the gas. The speeds of the motors can be adjusted easily and independently to provide efficient separation with a variety of external connections and under varying loads. The motors have enough torque to handle "slug" flow conditions without stalling. The flow-through arrangement ensures both effective separation and a compact package.



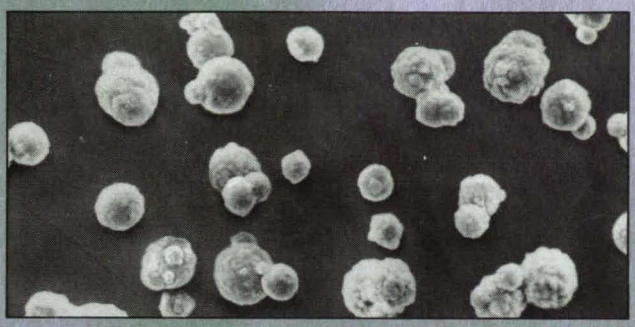
The **Liquid is Expelled** radially outward from the separator rotor. Entrained gas is released, flows axially through the rotor, and leaves through the fan at the downstream end.

This work was done by John Mann of United Technologies Hamilton Standard for **Johnson Space Center**. *No further documentation is available.*
MSC-21877

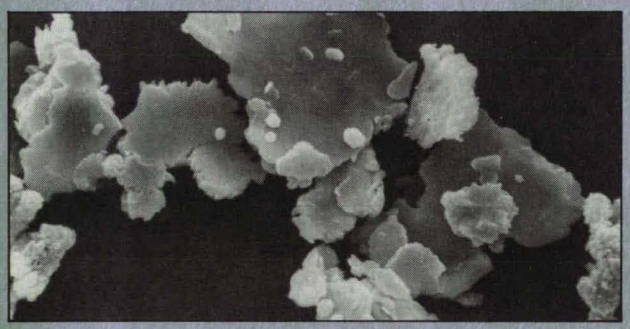
SPECIFY INCO SPECIALTY POWDERS FOR WIDE RANGE OF ELECTRONIC APPLICATIONS



Inco Type T 287 Filamentary Powder, particle size (FSSS) 2.6-3.3 microns, apparent density 0.75-0.95 g/cc, relative surface resistivity 0.30 ohms per square (□).



Novamet Silver Coated Nickel Spheres, 15% Ag, 2.5 g/cc apparent density, particle size 10 microns, screen mesh 99%-250, surface resistivity 0.03 Ω/□.



Novamet HCA-1 Flake, screen mesh 98% minus 400, apparent density 0.90 g/cc, thickness 1.0-1.1 microns, surface resistivity 0.25 Ω/□.

Novamet Nickel Coated Graphite, 60% fully encapsulated Ni, apparent density 1.6 g/cc, particle size (FSSS) 100 microns, screen mesh 63% −150/+250, surface resistivity 0.3 Ω/□.

Inco Specialty Powder Products now has a wide range of nickel and coated powders with exceptional conductive and magnetic properties. These properties make them ideal for a spectrum of electronic applications such as conducting film technology, coatings, adhesives, gaskets and EMI shielding.

EXTENSIVE PRODUCT RANGE

The development of computer processed control coupled with the continuous powder production improvements enables us to meet your most stringent powder specifications for electronic applications.

In addition to the products pictured above, INCO SPP has available the following high performance powder products. Novamet Conductive Nickel Spheres, particle size (FSSS) 8-9 microns, apparent density 3.2-3.5 g/cc, surface resistivity 1.0 ohms per square. Novamet 525 Conductive Nickel Pigment, screen mesh 100% minus 400, particle size 3.2 microns, 0.65 BET surface area m^2/g, surface resistivity 0.35 ohms per square. Silver Coated Nickel Flake, 15% Ag, 2.6 g/cc apparent density, particle size (FSSS) 15 microns, screen mesh 99% minus 200, surface resistivity 0.04 ohms per square.

Magnetic ferrites and surge arrestor applications also use our specialized range of nickel oxides. High Purity Black Nickel Oxide, 77.2% Ni, BET 75 (m^2/g) particle size (FSSS) 5.2 microns, minus 325 mesh 99% plus. Green Nickel Oxide, 78.5% Ni, BET 3 (m^2/g) particle size 1.6 microns, −325 mesh 100%.

Inco Specialty Powder Products is your unique source for custom fitting high performance powders into electronic applications. Our customer focused, worldwide marketing service group is ready to help you with your current and future needs.

For more information write INCO Specialty Powder Products, Dept. 1-90, Park 80 West-Plaza Two, Saddle Brook, NJ 07662

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Shin-Muromachi Building, 4-3 Nihonbashi-Muromachi 2-Chome, Chuo-ku, Tokyo 103 Japan
1-3 Grosvenor Place, London SW1X7EA England
15/Fl Wilson House, 19-27 Wyndham Street Central, Hong Kong

Circle Reader Action No. 452

Removing Solids From Supercritical Water

Salts and other solids are separated via impingement and filtration.

Lyndon B. Johnson Space Center, Houston, Texas

An apparatus removes precipitated inorganic salts and other solids in a water-recycling process. The apparatus is designed for use with oxidation in supercritical water (water above its thermodynamic critical point of T = 374°C and P = 220 bar), which treats wastes and yields nearly pure water. The product of the oxidation reaction is supercritical water containing sticky, undissolved solids that will foul and corrode equipment if allowed to continue downstream.

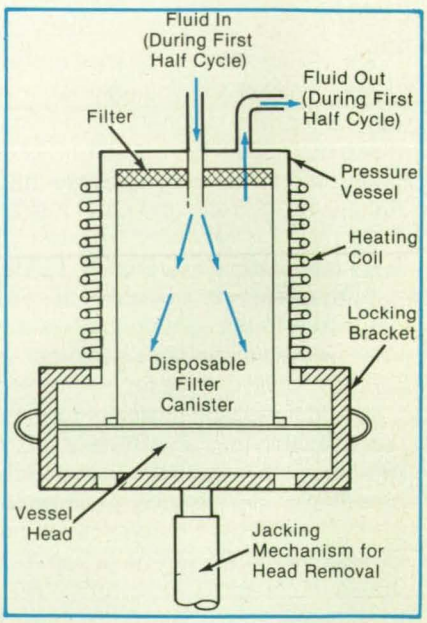
In some terrestrial systems or in the absence of gravity, the solids will not drop into a cooler liquid zone, where they could be redissolved and withdrawn. The new apparatus, therefore, relies on the tendency of the sticky precipitate to adhere to the walls of a container.

The apparatus includes a cylindrical pressure vessel containing a disposable canister (see figure). The effluent from the oxidation reaction enters the canister through a pipe at top center. In some cases, the oxidation of organics and the precipitation of inorganics may continue as the effluent flows into the canister. Solid particles in the stream impinge on the wall of the canister with high momentum and stick to it, forming a porous cake. The stream exits through a filter at the top of the canister. The flow is then reversed; any particles remaining in the stream cannot pass through the filter at the canister exit and therefore build up on it. The pressure vessel is kept at a temperature of 450°C or higher to ensure the collection of dry solids.

In about 90 days, the canister will have accumulated a suitable quantity of solids. The system will then be shut down, the head of the filtration pressure vessel will be taken off, and the impingement/filtration canister will be removed and replaced by a fresh one.

This work was done by Glenn T. Hong of Modar, Inc., for **Johnson Space Center**. *For further information, Circle 64 on the TSP Request Card.*

MSC-21382



Supercritical Water Carries Solid Particles into the vessel and exits without them. Heating coils and insulation around the vessel keep it hot. A locking bracket seals the vessel but allows it to be easily opened for replacement of filled canisters.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Simplified Modeling of a Helicopter

A mathematical model with minimum complexity is developed.

A report discusses the development of a minimum-complexity mathematical model of a helicopter for use in a flight simulator. This development has been motivated by the computational delays, costs, long development times, and inflexibility of the sophisticated models now in use. The new model overcomes these disadvantages and provides a better engineering understanding of those features pertaining to handling qualities that are apparent to the pilot who uses the simulator.

Previously, mathematical modeling of the flight characteristics of helicopters has involved either great complexity in the effort to achieve high computational fidelity or oversimplified linearized stability-derivative forms that are easier to manage but which may lack fidelity or be restricted to small operating ranges. In the compromise approach taken in this study, one starts with a model of minimum complexity and adds only just enough complexity to simulate the handling qualities of the helicopter adequately over the full operating range, without attempting to simulate effects that the pilot cannot perceive. The model must be affordable, manageable, easily verifiable, and modifiable, and must enable the engineer to determine clear cause-and-effect relationships between parameters of the model and responses perceivable by the pilot. The model is required to be modular to provide adaptability; for example, to enable the substitution of alternative submodels of the rotor, lifting surfaces, control subsystems, vibrational modes, and pilots.

The report describes the development of the model in five sections. Section I is an introduction that describes the motivation and the general approach. In section II, the technical approach to modeling is described in detail to establish the theoretical foundation for the model. The features and components of the model are described. The model is used to represent a Bell AH-1S Cobra helicopter.

In section III, the matching and estimating procedures used to obtain the parameters of the model are described. The sample version of the AH-1S is used as a specific example. The model is then exercised, and the estimated parameters are varied to tune the model to fit data on performance. Section IV describes several methods of checking the computer code of the model. The size of the model and the modular format are conductive to efficient checking. Methods for the verification of the equations of the model are then presented and illustrated by application to the AH-1S example.

In section V, possibilities for the extension or modification of the model are introduced to demonstrate flexibility. The potential for increased effectiveness of simulation by use of these extensions and modifications is revealed and explained in terms of the approach taken to the modeling process.

This work was done by Robert K. Heffley and Marc A. Mnich of Manudyne Systems, Inc., for **Ames Research Center**. *Further information may be found in NASA CR-177476 [N88-29819], "Minimum-Complexity Simulation Math Model."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12307

Fabrication Technology

Hardware, Techniques, and Processes

Tool for Installation and Removal of Welding Electrodes

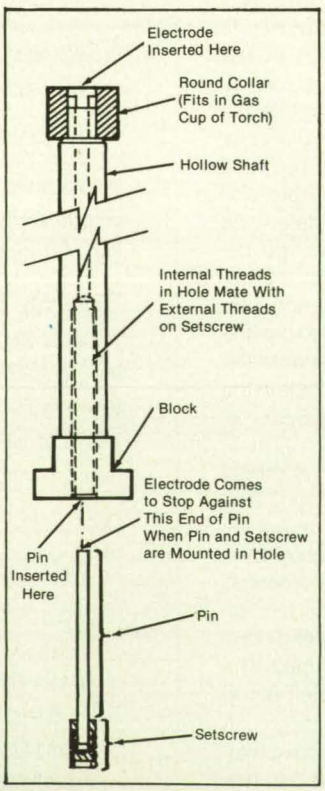
The tool helps align electrodes of different diameters.

Marshall Space Flight Center, Alabama

A special tool assists in the installation and removal of the welding electrode in a welding torch equipped with a through-the-torch vision system. The tool is designed specifically for use within the unique configuration of the weld block and the welding-electrode collet of this torch.

The tool centers itself in the torch block and sets the length of protrusion of the electrode from the gas cup of the torch. It can be used with long or short gas cups. It can handle electrodes of 1/16 in. (1.6-mm), 3/32 in. (2.4-mm), and 1/8 in. (3.2-mm) diameter.

The tool includes a hollow round shaft equipped with a rectangular block at one end and a round collar at the opposite end (see figure). An electrode rod is inserted in the hollow core of the shaft at the collar end and pushed in until it comes to a stop against a pin held in place by a setscrew at the block end. The setscrew can be turned to change the position of the stop and thereby adjust the distance through which the electrode will protrude after the subsequent installation.



The **Tool Can Be Inserted** easily into the welding torch after the welding electrode has been loaded into the hollow shaft.

The collared end of the tool is placed in the gas cup to center the electrode in the collet. The collet is made to grasp the inner end of the electrode, and the tool is removed. The tool can also be used as a receptacle to catch the electrode when the collet is loosened to release the electrode.

This work was done by Jeffrey L. Gilbert and David A. Gutow of Rockwell International Corp. for **Marshall Space Flight Center**. *For futher information, Circle 85 on the TSP Request Card. MFS-29841*

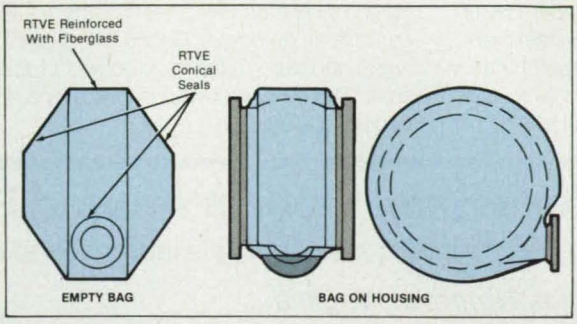
Protective Cover for Degreasing

A tightly fitting elastomeric cover exposes only surfaces to be degreased.

Marshall Space Flight Center, Alabama

A cover protects the outside surface of a pump housing when the housing is immersed in a trichloroethylene or other degreasing solvent. The interior surface and flanges of the housing can thus be degreased while the outside surface stays dry. The cover is needed because outer surface of the particular housing is plated with a foam that would be damaged by the solvent.

The cover is a bag made of fiberglass-reinforced room-temperature-vulcanizing elastomer (RTVE). Holes on opposite faces of the bag allow it to be slipped over the housing flanges and inlet (see figure). The RTVE then forms a tight seal that prevents degreasing solvent from entering the bag and wetting the outer surface of the housing.



Openings in the Bag fit over flanges to form a leak-proof seal around the outer surface of the housing.

This work was done by Edwin D. Wolff of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-29748.

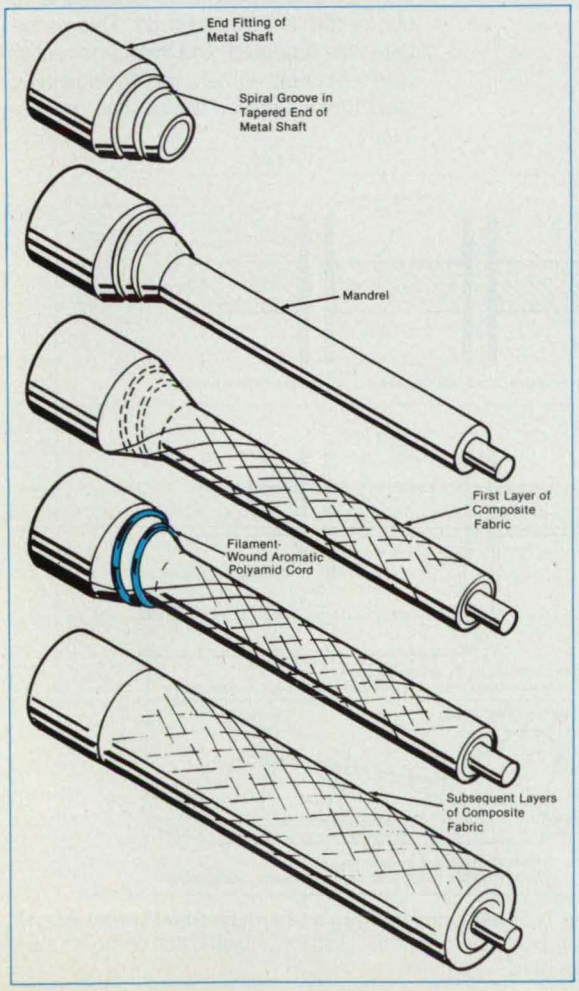
Metal-to-Composite Shaft Splice

A strong, lightweight shaft is formed without awkward bolted flanges.

Lewis Research Center, Cleveland, Ohio

A manufacturing technique joins a shaft of composite material to a metal shaft. The technique can be used to join a shaft of graphite-fiber-reinforced epoxy to

Composite and Metal Portions of a Shaft are joined by winding the composite portion onto the outer surface and into the spiral groove of the metal portion. The groove and the composite material in it constitute a structural bond. If opposing spiral grooves are used, then the two shafts are locked together against torques in both directions.



one of titanium, for example, so that large torques can be transmitted, as in helicopter rotor shafts. The technique avoids bolted flanges. Such flanges are difficult to fabricate in composite materials; they require painstaking manual layup to orient the fibers for carrying torsion loads.

A spiral groove is cut in the tapered end of the metal shaft (see figure). A steel mandrel is inserted in the end of the metal shaft. A thin layer of composite fabric is wound on the tapered end of the metal shaft and on the mandrel. A filament-wound aromatic polyamide cord is wrapped into the spiral groove on the tapered end. Additional layers of composite fabric are wound tightly on the tapered end and the mandrel, retaining the cord in the groove. Finally, the assembly — which has been preimpregnated or injected with a resin binder — is cured in an autoclave. Curing forms an integral structure at the tapered end of the shaft. The spiral groove prevents slippage under high torque.

The mandrel is removed after curing. The composite portion of the shaft then constitutes a lightweight structure that is strong in torsion, while the metal part of the shaft provides a bearing surface that can react both axial and lateral loads.

This work was done by Jules Kish, Dean Nguyen, and Tim Lauder of United Technologies, Sikorsky Aircraft for **Lewis Research Center**. *For further information, Circle 165 on the TSP Request Card.*
LEW-14910

Casting Stainless-Steel Models Around Pressure Tubes

The survivability of thin-wall stainless-steel tubing is increased to nearly 100 percent.

Langley Research Center, Hampton, Virginia

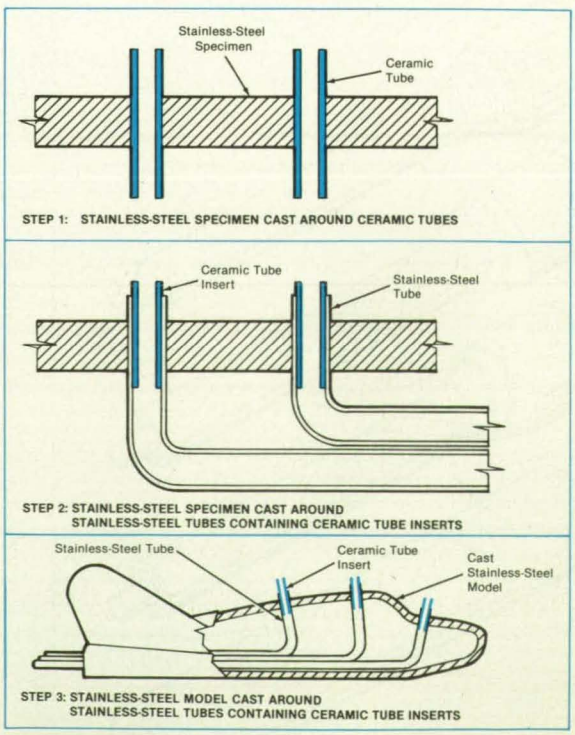
Using a new technique developed at NASA Langley Research Center, a stainless-steel model was successfully cast around thin-wall stainless-steel pressure tubes. For many years, this was considered infeasible. Heretofore, success could be achieved only if the stainless-steel tubes were cast in either gunmetal or aluminum, inasmuch as the melting temperatures of these metals are lower than that of steel.

Previous attempts to cast stainless steel around stainless-steel tubes were unsuccessful because (1) the tubes contain molybdenum and/or titanium, the melting points of both of which are higher than that of steel, and (2) as a consequence, the tubes became stringy and spaghettilike when molten metal flowed over them. As a result, the tubes cracked and filled with molten steel. Various attempts to protect the tubes and keep them clear of molten metal proved unsuccessful.

In the first step of an experiment in the new technique, alumina ceramic tubes of 0.010-in. (0.25-mm) wall thickness were set in place while a stainless-steel test specimen was cast around them (see figure). The ceramic tubes survived the thermal shock, the intense heat, and the bearing load of the steel casting. The integrity of the tube holes was sustained, and all tubes were clear of molten metal. Ceramic tubes were also incorporated into a centrifuge-cast stainless steel specimen, identifying this technique as a viable concept for making stainless-steel pressure models.

The next step was to insert thin-wall ceramic tubes into stainless-steel tubes to determine whether the thin-walled ceramic tubes would prevent molten steel from penetrating and filling the stainless-steel tubes. It was found that the ceramic tubes did, indeed, have this effect and that the process was repeatable.

In the last step of the experiment, eight stainless-steel tubes with ceramic inserts were placed into the mold of a model, and the model was cast in stainless steel by use of the lost-wax method. This procedure was repeated, and the same results were obtained; namely, that the stainless-steel tubes survived the casting process intact.



The **New Technique for Casting a Stainless-Steel Model** around strainless-steel pressure tubes was investigated and demonstrated in a three-step experiment.

This technique has improved the state of the art in pressure-model castings and reduced the cost associated with machining a complete model from a stainless-steel blank. Prior to the advent of this technique, the failure rate of stainless-steel tubes cast in stainless steel was nearly 100 percent. With this technique the rate of survival of stainless-steel tubes cast in stainless steel should be nearly 100 percent.

This work was done by Peter Vasquez and John R. Micol of **Langley Research Center**. *No further documentation is available.*
LAR-14213

Magnetic Location Indicator

A simple tool shows where a magnetic field is most intense.

John F. Kennedy Space Center, Florida

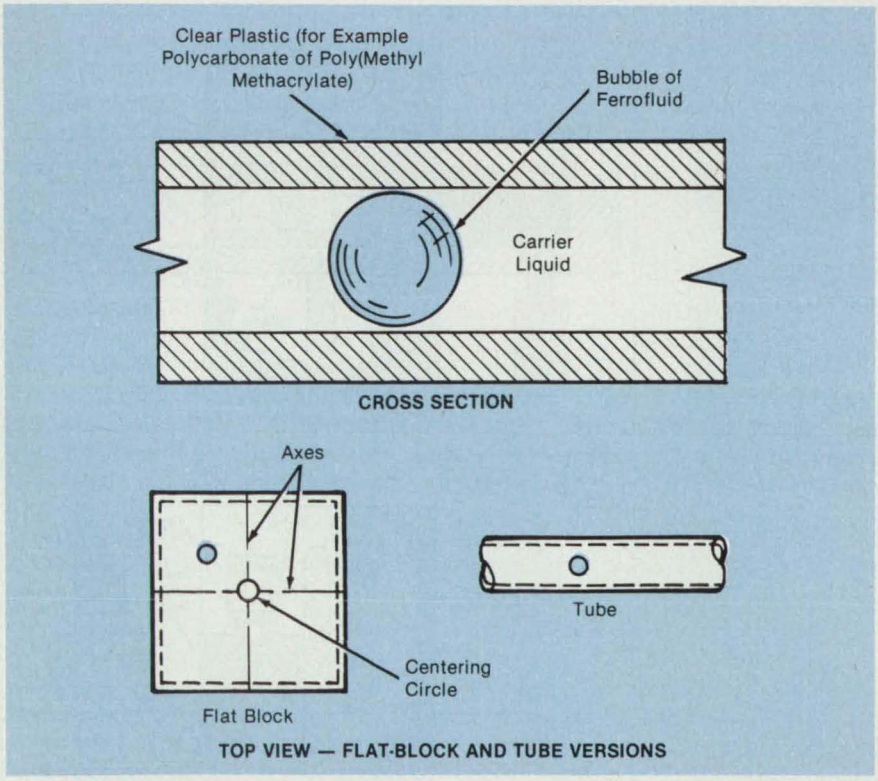
A ferrofluidic device indicates the point of highest magnetic-flux density in a workspace. The device consists of a bubble of ferrofluid in an immiscible liquid carrier in a clear plastic case. The bubble — dyed for easy viewing — migrates to the point where the magnetic-flux density is greatest.

The ferrofluid is a stable colloidal suspension of magnetic particles in a liquid that has chemical and physical properties similar to those of the carrrier liquid surrounding it. When a magnetic field is applied to a bubble of ferrofluid, the particles orient themselves along the magnetic field almost immediately. In a graded magnetic field, the particles experience forces that draw the entire bubble to the point of highest field strength.

The container may be a flat hollow block or a tube made of a transparent material such as polycarbonate (see figure). If the ferrofluid liquid and the surrounding carrier liquid are formulated so that they have the same density, the effect of gravity is negated, and the device can be used in a vertical plane as well as a horizontal plane. A light oil can be used for the ferrofluid liquid, and distilled water can be used for the carrier liquid, for example.

The device can be used to find the point on a wall corresponding to a known point on the opposite side of the wall. A magnetic source would be placed at the known point. An operator would slide the device across the opposite side of the wall. The point at which the ferrofluid bubble centers in the viewing glass would then be directly opposite the known point.

This work was done by Thomas W. Stegman of Lockheed Space Operations Co. for **Kennedy Space Center**. *For further information, Circle 50 on the TSP Request Card.*
KSC-11442



The **Ferrofluid Bubble** can be used in a flat block or a tube. The axes of the centering circle on the flat-block version are used to mark the location of maximum flux density when the bubble is in the circle.

Automated Blast Cleaner

An apparatus cleans surfaces quickly and consistently.

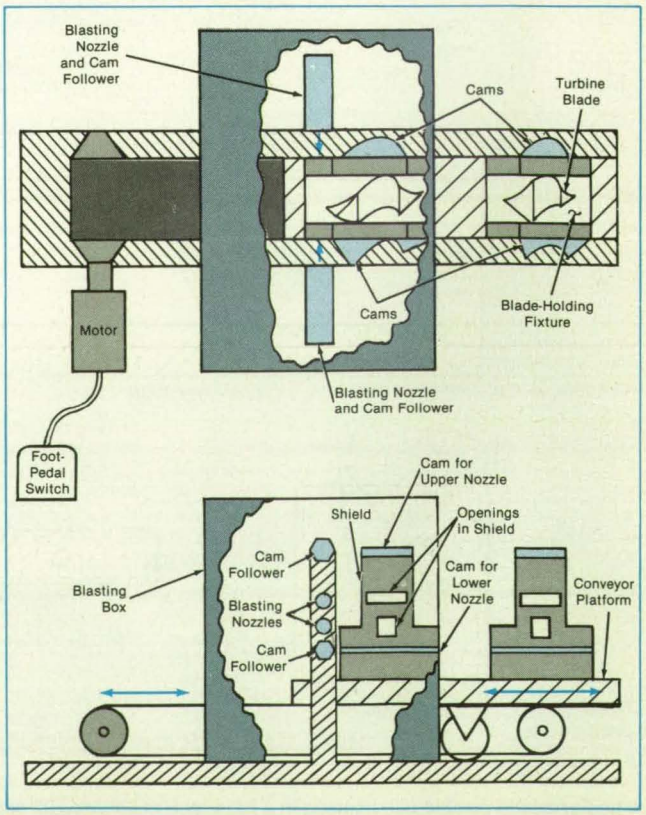
Marshall Space Flight Center, Alabama

An automatic grit-blasting machine removes melted-layer residue from electrical-discharge-machined surfaces of turbine blades. The automatic control system of the machine provides a steady flow of grit and maintains the blast nozzles at the proper distance and in the correct orientation perpendicular to the surface being blasted, regardless of its contour. The automatic control system eliminates localized excessive blasting and the consequent excessive removal of underlying material, blasting of adjacent surfaces, and missed areas, all of which occurred in the previous manually controlled grit-blasting operation.

An operator installs a blade in one of two fixtures on a conveyor and presses a foot pedal to start the machine. The conveyor moves the blade into a blasting box. As the blade approaches the grit-blast nozzles, cams on the conveyor engage rollers on each of the nozzles to maintain each nozzle at a constant distance from the surface to be blasted. Ramps on the ends of the cams activate switches to start and stop the flow of grit at the ends of the surfaces to be blasted.

There are two pairs of nozzles on opposite sides of the blade. They tilt and slide inward and outward as directed by the cams and the rest of the automatic control system. The flow of grit is stopped after 15 seconds, and the blade leaves the blast box. Meanwhile, the operator has loaded another blade in the other fixture, and the cycle is repeated. The machine can process two blades per minute—one-fifth the time of the manually controlled procedure.

This work was done by Isaiah R. Pickett and Alyce R. Yulfo of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 131 on the TSP Request Card. MFS-29774*



The **Conveyor Platform** carries turbine blades in fixtures through the blasting box. Cams on the fixture help to control the blasting nozzles.

Mathematics and Information Sciences

Approximate Solutions of Equations of Steady Diffusion

Rigorous analysis yields reliable criteria for "best-fit" functions.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved "curve-fitting" method yields approximate solutions to the differential equations of steady-state diffusion. The method is quite general: it applies to problems in which (1) rates of diffusion depend linearly or nonlinearly on concentrations of diffusants; (2) approximate solutions are analytic or numerical; and (3) boundary conditions are of the Dirichlet type (concentration specified on the boundary), of Neumann type (normal component of gradient of concentration specified on the boundary), or a mixture of both types. The method could be applied beneficially, for example, to the equations for the diffusion (excluding drift motions) of charge carriers in semiconductors in which the mobilities and lifetimes of the charge carriers depend on their concentrations.

Heretofore, it has been common practice to select a "best-fit" approximate solution from a set of functions by use of any of a number of variational methods in which one seeks an extremum of a functional, *J*, that gives some measure of the error in the approximate solution. This prior approach is not rigorous: the stationary value could represent a local or global maximum or minimum, and might not represent the true best-fit solution under some conditions.

The improved method is based on a rigorous analysis, Provided that the differential equation for diffusion, the boundary conditions, and the set of trial functions satisfy a set of fairly lenient criteria, the improved method enables one to proceed almost as casually as in the prior, less-rigorous variational methods. In comparison with the prior methods, the improved method applies to a more-general class of boundary conditions and imposes less-severe requirements upon smoothness of functions.

The improved method is also more reliable in that it defines "best fit" by specifying an improved error-measure functional that reaches its true global minimum of zero when the trial function is the exact solution. One of the advantages of this method is that even if a set of trial functions does not contain the exact solution or even the best-fit approximate solution, one can still compare the available functions with each other to determine which fits better in the sense that it makes the error measure smaller.

This work was done by Larry D. Edmonds of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 36 on the TSP Request Card. NPO-18285*

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Validation of Critical Knowledge-Based Systems

The adaptation of techniques developed for the validation of flight systems is discussed.

A report discusses an approach to the verification and validation of knowledge-based systems. Also known as "expert systems," these are electronic control and/or monitoring systems that include computer programs and equipment capable of certain kinds of "learning" or adaptation to complicated situations. The report is concerned mainly with the development of methodologies for the verification of knowledge-based systems that are critical to flight-research systems; e.g., fault-tolerant control systems for advanced aircraft. The subject matter may also have some relevance to knowledge-based systems that would control medical life-support equipment or commuter railroad systems, for example.

The author notes that heretofore conventional systems critical to flights and to the successes of the missions of those flights have been verified, qualified for flight, and validated by use of well-known and well-established techniques. These techniques define the validation methodology used for such systems. The methodology encompasses testing, peer review, abstract models, simulations, and flight validation. This methodology also relies, in large part, on engineering judgment and tradition that has evolved from experience.

The justification for the extension of the conventional validation methodology to knowledge-based systems is the similarity of current knowledge-based systems to conventional systems in terms of complexity and function. To verify, qualify, and validate knowledge-based systems, the methodology used for conventional systems must be addressed, and the applicability and limitations of that methodology to knowledge-based systems must be identified. The author presents an outline of how this approach to the validation of knowledge-based systems is being developed and used at the Dryden Flight Research Facility of the NASA Ames Research Center.

After presenting introductory remarks and definitions, the report proceeds to discuss a methodology for the verification and validation of conventional, embedded, flight-critical control systems. It then discusses the application of that methodology to knowledge-based systems. The validation of a simple knowledge-based system is illustrated with the example of the altitude-command autopilot subsystem of the F-15 airplane. This is followed by a discussion of the limitations of validation methodology for knowledge-based systems.

The final section of the report offers several conclusions. One is a list of important differences between conventional and knowledge-based systems. Another is a reiteration of a statement by previous authors to the effect that a methodology for the validation of fault-tolerant knowledge-based systems of ultrahigh reliability must be based on a judicious combination of logical proofs, analytical modeling, and experimental testing. The report ends with criticism of what the author considers to be the mystification and obfuscation practiced by some developers and advocates of knowledge-based systems.

This work was done by Eugene L. Duke of **Ames Research Center**. *Further information may be found in NASA TM-100442 [N88-25207], "Application of Flight Systems Methodologies to the Validation of Knowledge-Based Systems."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703)487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12427

Recursive Filtering and Smoothing in Robot Dynamics

Techniques developed originally for electronic systems are also useful for multibody mechanical systems.

A report summarizes methods developed by the author to solve the nonlinear forward-dynamics problem for a robot of multiple-link arms connected by joints. (The forward-dynamics problem is to find the joint-angle accelerations from the torques applied to the joints.) The primary objective of the paper is to show the equivalence between recursive methods of dynamical analysis and some filtering and smoothing techniques from state-estimation theory. The author's work in demonstrating this equivalence is noteworthy because the state-estimation theory was originally developed for the analysis of linear electrical and electronic, rather than nonlinear mechanical, systems.

Although the overall dynamical equations of a multiple-arm robot are nonlinear, they include a linear relationship between the applied torques and the joint-angle accelerations at any given time. A state-space mathematical model can be used to characterize this linear relationship. The states in this model are the forces and torques (denoted here collectively as "spatial forces") applied to each link at each joint. The state-space model is spatially recursive in the sense that the spatial forces are represented as being propagated from each link to the next via the joint between them. The propagation at each joint is represented by a transition matrix, and the inertial properties of each link are represented by an inertia matrix. The costates in the model are the linear and angular accelerations of the joints (denoted here collectively as "spatial accelerations").

The author has observed that such a model makes it possible to use the highly developed techniques of the theory of linear systems — particularly, the recursive filtering and smoothing techniques of state-estimation theory for systems in which the inputs and outputs are sampled at discrete times. An algorithm for the solution of the forward-dynamics problem can be represented by the predictor/corrector architecture of the Kalman filter. The moments applied to the joints are fed as inputs to the filtering stage, which produces a sequence of spatial constraint forces acting on the joints. The differences between the actual and predicted applied torques are fed to the smoothing stage, which produces a set of spatial accelerations and a corresponding set of joint-angle accelerations.

One of the advantages of the filtering-and-smoothing approach is that it leads to the discovery of new physical and mathematical insights that would otherwise be difficult to discover. For example, there is an equivalence between the spatial-inertia matrix and a covariance matrix in state-estimation theory. Other advantages of the filtering-and-smoothing approach are that it is well known and widely accepted, considerable experience has been gained in both analysis and computation, and standardized software to implement filters and smoothers is available.

This work was done by Guillermo Rodriguez of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Spatially Recursive Filtering and Smoothing for Robot Dynamics," Circle 42 on the TSP Request Card.*
NPO-17787

Managing Data From Signal-Propagation Experiments

Data-acquisition hardware and software are described.

A report discusses a system for the management of data from the Pilot Field Ex-

periment (PiFEx) program, which consisted of a series of experiments on the propagation of signals from a transmitter at one fixed location to a transponder on a tower at another fixed location and from the transponder to a mobile receiver in a van. The purpose of these experiments was to simulate the signal-propagation conditions of a land-mobile/satellite communication system.

The report is in the form of a manual for training a computer operator in the use of the software component of the data-management system. It begins with brief descriptions of the equipment and procedures used in the experiments, the data-acquisition system, the format in which the data were stored en masse in the data-acquisition system, the conversion of the data to a different format for subsequent processing, and the transmission of the data to the minicomputer that is the hardware component of the data-management system. With the foregoing as background, the report goes on to provide instructions in the use of the data-management software.

The data (both from originally digital and from sampled, digitized analog signals) are arranged in four sets. The first set, called "propagation data," includes the in-phase and quadrature voltages of the reference and pilot channels. The second set, called "loop data," pertained to the dynamic and static errors of the phase-lock loop of the receiver. The third set, called "antenna data," contains normalized differences, logarithms of sums, and temperatures. The fourth set, called "digital data," includes azimuthal positions of the antenna on the van, data from a gyroscope, and the speeds of the van. The fourth set also includes a file called "spare data" for future addition of digital sources.

The four sets of data acquired during each 2.5-minute interval are grouped together into a file in ASCII format, and the collection of such files constitutes the data transferred en masse to the minicomputer. The data-management system automatically divides the mass of data into individual files from each experiment. The software includes programs in the FORTRAN and C languages that process data into quantities useful in assessing the results of the experiments. Available outputs include the following:

- The probability, as a function of the signal level, that the signal will exceed that level;
- The probability density of a given signal level as a function of the level, and a least-squares fit to the proper Rician density function;
- The frequency of occurrence of fades of a given duration as a function of the duration;
- A downloadable file of signal levels and phases as functions of frequency or time for conversion into graphical output via the AKPLOT routine; and
- The Fourier transform of the first 1,024 samples of a designated input data file.

This work was done by Anil V. Kantak of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Unix-Based Data Management System for the Mobile Satellite Propagation Experiment," Circle 34 on the TSP Request Card. NPO-17411*

Spurious Results of Explicit Runge-Kutta Integrations

Steady-state numerical solutions do not necessarily converge to analytical solutions.

A report discusses the spurious numerical solutions that are sometimes produced by explicit Runge–Kutta numerical integrations. These spurious numerical solutions include steady-state solutions (fixed points), periodic orbits, and chaotic phenomena. Among these spurious numerical solutions, the spurious steady-state solutions are the most difficult to detect when one uses the time-dependent approach to obtain steady-state numerical solutions in nonlinear partial differential equations.

The study focuses on the ordinary dif-

ferential equations $\dot{U} = \alpha\dot{U}(1-U)$ and $\dot{U} = \alpha U(1-U)(b-U)$. Five different numerical-integration schemes are applied to these equations, and the results are investigated both analytically and numerically. The first scheme, included for comparison, is the explicit Euler scheme. The second scheme, which is of the second-order Runge–Kutta type, is a refined version of the explicit Euler scheme and is called the "modified" Euler scheme. The third scheme, also of the second-order Runge–Kutta variety, represents a further refinement of the explicit Euler scheme, and is called the "improved" Euler scheme. The fourth scheme, called the Heun scheme, is of the third-order Runge–Kutta type. The fifth scheme is a fourth-order Runge–Kutta scheme.

The fixed points and periodic orbits of the four Runge–Kutta schemes are investigated and compared with those of the explicit Euler scheme, which is known to yield only the fixed points of the differential equation. It is shown that not only do these Runge–Kutta schemes produce spurious fixed points, but, in addition, some of the spurious features manifest themselves below the linearized stability limit for the correct fixed points. This raises the possibility of erroneous results when such schemes are applied to problems for which the initial data and the correct solutions are not known a priori.

It is also observed that multiple orbits of a given period can coexist, the particular orbit selected by a particular integration scheme depending on the initial data. Thus, the bifurcation diagram obtained by use of a single starting value may appear to be missing branches of orbits of higher order.

This work was done by H. C. Yee of **Ames Research Center**, *P. K. Sweby of the University of Reading, and D. F. Griffiths of the University of Dundee. Further information may be found in NASA TM-102819 [N90-22340] and NASA TM-102820 [N90-22339], "On Spurious Steady-State Solutions of Explicit Runge–Kutta Schemes."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12771

Numerical Asymptotic Solutions of Differential Equations

Numerical algorithms are derived and compared with classical analytical methods.

Classical asymptotic analysis of ordinary differential equations derives approximate solutions that are numerically stable. However, the analysis also leads to tedious expansions in powers of the relevant parameter for a particular problem. In an alternative method, the expansions are replaced with integrals that can be evaluated numerically. The resulting numerical solutions retain the linear independence that is the main advantage of asymptotic solutions. Examples, including the Falkner–Skan equation from laminar boundary-layer theory, illustrate the method of asymptotic analysis with numerical integration.

A study was concerned with the derivation of algorithms for the numerical solution of second-order linear differential equations. The algorithms were applied to several examples for comparison with analytical methods. The results of classical analyses were compared with those of the algorithms.

The derivation of an algorithm began with the application of Newton's method to first-order nonlinear equations. The resulting first-order equation is the simplest example of solving differential equations by Newton's method. The results derived for first-order nonlinear differential equations were readily extended to nonlinear second-order equations. To test the concept for second-order equations, the third-order system was solved by a modified form of Newton's method. The modification reduces each cycle of iteration to a combination of the solution of a linear second-order equation with the integration of a simple first-order equation. The study showed that it is feasible to achieve the linear independence for the asymptotic theory for general cases while avoiding algebraic manipulations for each special case.

Solution of differential equations is a common requirement in the design of any engineering system. The accurate control of processes may well be based on the automatic solution of differential feedback equations that connect inputs with measured outputs. This study may be the first to show, by example, that numerical integration of asymptotic solutions of ordinary differential equations yields accurate results in short runs on microcomputers, reducing the cost of computing time and the capital expense for equipment for frequently required computations.

This work was done by Gaylen A. Thurston of **Langley Research Center**. *Further information may be found in NASA TM-100650 [N90-15401], "Numerical Integration of Asymptotic Solutions of Ordinary Differential Equations."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LAR-14415

Life Sciences

Sequences of Amino Acids for Human Serum Albumin

Smaller biologically active polypeptides can be made.

Marshall Space Flight Center, Alabama

The recent determination of the structure of human serum albumin based on a new crystalline form has revealed the portions of the sequence of amino acids that account for the outstanding binding properties of the serum albumin molecule. As a result, sequences of amino acids have been defined for use in making polypeptides one-third to one-sixth as large as the parent human serum albumin molecule. These smaller, chemically stable peptides have diverse applications including service as artificial human serum and as the active components of biosensors and chromatographic matrices.

At present, there are thousands of applications of serum albumin proteins made from the native serum albumins from human and bovine sources. There are two major disadvantages to the use of these substances: plasmas isolated from natural sources can be contaminated by viruses [e.g., human immunodeficiency virus (HIV) and Herpes], and larger (intact) proteins like the serum albumins become denatured more readily and are more difficult to produce by genetic engineering. In applications that involve the production of artificial sera from the new sequences, there is little or no need to be concerned about viral contaminants. Furthermore, the smaller genetically engineered polypeptides are more easily expressed and produced in large quantities, making commercial isolation and production more feasible and profitable.

The new sequences are the following:

1 to (101-117) (human)
1 to (101-117) (bovine)
1 to (177-199) (human)
1 to (175-197) (bovine)
391 to (487-505) (human)
390 to (485-514) (bovine)
391 to 585 (human)
390 to 582 (bovine)

Alternative useful sequences could also be chosen by adding or deleting leading and/or trailing amino acids in these sequences. Other alternative sequences can be chosen by changing specific amino acids to increase or decrease the binding affinities of various compounds or to reduce the likelihood of antigenic responses.

This work was done by Daniel C. Carter of **Marshall Space Flight Center**. *For further information, Circle 67 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28402.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Using Satellite Data To Map Crops

An inventory of California's Central Valley demonstrates mapping procedures.

A report describes a 4-year cooperative project to develop procedures for mapping land used to grow major crops in California. The participants used images and data from the Landsat Earth-observing satellite as well as ground survey data. The U.S. Department of Agriculture and the University of California acquired the satellite and survey data, and the California Department of Water Resources and NASA processed the data.

The procedures were tested by making an agricultural land-use inventory of the Central Valley of California. The inventory furnished a map and estimates of acreage devoted to alfalfa, almonds, cotton, grapes, tree fruits, walnuts, and other important crops. The inventory was completed on schedule, demonstrating the plausibility of the approach.

The researchers found, however, that further work is needed to develop the data-processing system. The data were processed on a network of workstations and a mainframe computer. Although the network worked well for communication and small-scale transfers of data, it was not adequate — and was not expected to be — for transferring large sets of data. Unless a high-speed link is set up between the mainframe computer and the workstations, it will be necessary to transfer data on magnetic tape. This is likely to reduce efficiency and cause delays.

The report gives background on the project, describes the cooperative agreement, discusses the procedures for the inventory (which occurred during the year 1985), analyzes the inventory data, and presents detailed conclusions and recommendations for the processing and use of the Landsat and ground-survey data. An appendix lists the modules in PEDITOR, the software package developed as part of the project and currently in use by the USDA. Other appendices list recommendations that contributed to the design of the 1985 inventory and a robust regression-estimation technique that was tested with 1985 data.

This work was done by Christine A. Hlavka and Edwin J. Sheffner of **Ames Research Center**. *Further information may be found in NASA TM-100073 [N89-13824], "The California Cooperative Remote Sensing Project: Final Report."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. ARC-12580

Joint U.S./U.S.S.R. Study of Effects of Bed Rest

Horizontal and head-down positions were investigated at two research centers.

A report presents the results of a joint experimental study of the effects of bed rest conducted at Ames Research Center in California and the Institute for Biomedical Problems in Moscow. The study was conducted under identical conditions at both locations. In addition to generating useful scientific data, the study provided a basis for the comparison of physiological reactions and standardization of procedures and methods.

The experiments involved 14 days of pre-bed-rest control, 7 days of bed rest, and 10 days of recovery (subsequently changed to 14 days). Ten male subjects

participated at each site, five of them in a horizontal position and five in a 6° head-down position. During the experiments, biochemical and hormonal measurements were performed on blood and urine. Particular attention was given to electrolyte metabolism and kidney function, cardiopulmonary changes during rest and exercise, the influence of lower-body negative pressure, and the effects of incremental exercise on a bicycle ergometer in supine and sitting positions.

Both teams of investigators found that bed rest induced expected differences in biochemical endocrinological, hematological, and fluid-balance measurements, but almost no changes specifically attributable to the difference between the two bed-rest positions. For example, head-down subjects did not show significantly greater decreases in volumes of plasma, volumes of blood, and masses of red cells. There were also no significant differences in water loading. Overall, according to the clinical evidence, the physiological conditions that resulted from head-down bed rest more closely matched the conditions seen after space flight. For the most part, however, statistically significant differences between the two body positions were not observed.

This work was done by H. Sandler of **Ames Research Center** *and A. I. Grigoriev of the Institute for Biomedical Problems. Further information may be found in NASA TP-3037 [N90-28965], "Joint U.S./U.S.S.R. Study: Comparison of Effects of Horizontal and Head-Down Bed Rest."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone NO. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12809

Nutritional and Taste Characteristics of Algae

Chemical analyses were performed, and algal protein isolates were incorporated into some foods.

A report describes the investigation of the chemical composition of the blue-green alga *Synechococcus* 6311, as well as the preparation of protein isolate from the green alga *Scenedesmus obliquus* and the incorporation of this isolate into a variety of food products, which were evaluated for taste. This work is part of a program to investigate the growth of microalgae aboard spacecraft for use there as food.

Synechococcus 6311 was grown in KMC medium, its cells were ruptured by homogenization, and it was converted into an algal flour by freeze-drying. Analysis of this flour showed that, compared with flour made from *Scenedesmus obliquus* in a previous study, it had similar weight percentages of proteins (52.3 vs. 52.6), lower weight percentages of nucleic acids (3.6 vs. 6.0), and lower weight percentages of lipids and lipid-soluble pigments (12.6 vs. 15.0). The protein content of *Synechococcus* 6311 was high in the essential amino acid leucine and low in the essential amino acids methionine and tryptophan, in comparison with the standards of the Food and Agricultural Organization of the United Nations. The main fatty acids in *Synechococcus* 6311 were $C_{16:1}$, $C_{16:0}$, and $C_{18:1}$. The proportion of total unsaturated fatty acids in *Synechococcus* 6311 was lower than that in *Scenedesmus obliquus*. The only unsaturated fatty acids were the monounsaturated ones.

Part of the investigation included the preparation of foods that contained such isolated algal macronutrients as proteins and lipids, in addition to components derived from higher plants, including wheat flour, soy flour, potato powder and flakes, soy oil, and corn syrup. The flour used to prepare bran muffins and chocolate-chip cookies consisted of 5 weight percent algal protein isolate and 95 weight percent wheat flour. Two different flours used to prepare two different versions of fettuccine contained 5 and 10 weight percent, respectively, of algal protein isolate. Because the protein concentration of the algal isolate was 70 percent vs. approximately 12 percent for the protein concentration of wheat flour, the percentages of plant proteins supplied from algae to the four products ranged from about 20 percent to about 39 percent.

In the sensory analysis of the foods, the greenish colors resulting from the use of algal protein isolate were not found to be objectionable. The foods had a mild flavor described variously as "spinachy" or "grassy". This flavor was less detectable in the chocolate-chip cookies than in the bran muffins. The color and taste of the algae fettuccine were found to be pleasant and compared well with those of commercially available spinach and spirulina fettuccine. The textures of the various fettuccine products were judged to be satisfactory.

This work was done by M. Karel and Z. Nakhost of the Massachusetts Institute of Technology for **Ames Research Center**. *Further information may be found in NASA CR-177545 [N90-15591], "Utilization of Non-Conventional Systems for Conversion of Biomass to Food Components."*

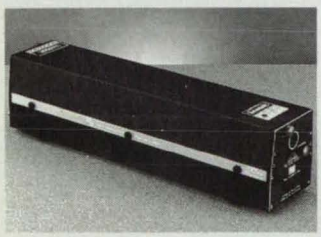
Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12800

New on the Market

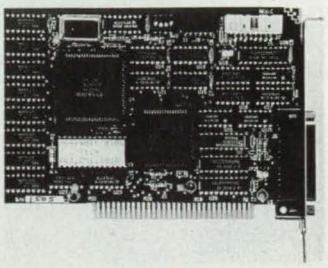
Research and Manufacturing Company, Tucson, AZ, has announced an **ultrasonic thermometer system** (UTS) with ceramic sensors for high-temperature measurements in chemical, metallurgical, and nuclear processes. By using ceramics as the sensing element, it eliminates complex material compatibility problems and provides excellent corrosion and chemical resistance. The microprocessor-based model 400 UTS offers RS-232, 4-20 mA, 0-10 v output signals for data acquisition and closed-loop automatic process control.
Circle Reader Action Number 788.

ObjectModeler, the first **CASE tool** that supports object-oriented analysis, design, and programming in a single module, has been introduced by Iconix Software Engineering Inc., Santa Monica, CA. The multi-user software enables concurrent repository access with collision detection, access controls, and global functions across a network.
Circle Reader Action Number 792.

The model C-105 **Nd:YAG laser** from CVI Laser Corp., Albuquerque, NM, provides 5-watt CW power output and better than 1% optical stability. Options include 1319 nm output and frequency doubling to 532 nm. The laser's enclosed design makes it suitable for medical, industrial, and academic laboratory applications.
Circle Reader Action Number 800.



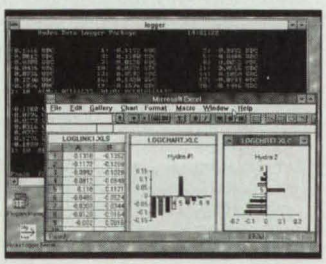
Scientists at Litton's Airtron division, Arlington, VA, have developed **technology to detect subsurface flaws and corrosion in materials**. The invention, a magneto-optic single crystal film, is used to monitor aircraft skin quality, and could be applied to quality control of metallic materials in production, and for routine safety tests. Incorporated into a magneto-optic eddy current viewing device, the crystal film has detected cracks as small as .040" long originating from rivet holes in aircraft structures.
Circle Reader Action Number 790.



Dale Electronics Inc., Columbus, NE, has introduced a **video adaptor card** that improves the display of color software. Called the PDS-30, the compact XT/AT half-card supports all IBM CGA and EGA modes on 200 to 400 line flat-panel displays and AT&T mode 40H on 400 line displays. Its circuitry automatically converts RGB color information to gray scale and hatching patterns, including normal and bold fonts active in both 40- and 80-column text modes. The card costs $360 each in 100-piece quantities.
Circle Reader Action Number 798.

Honeywell Inc., Plymouth, MN, has introduced a 16K x 1 **static memory** with true nonvolatile storage capability. The product, which incorporates proprietary magnetoresistive technology on top of a radiation-hardened SRAM, can be used to create nonvolatile electronic components for industrial control, satellite system, and commercial avionics applications. The nonvolatile information storage relies on the magnetic properties of deposited thin films, so there is virtually no wearout mechanism.
Circle Reader Action Number 794.

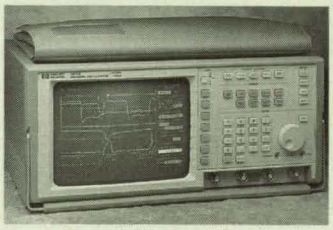
Hydra Data Logger **application software** from John Fluke Mfg. Co., Everett, WA, can now be used with Windows 3.0 for fast PC-based setup, configuration, and data collection with Hydra data acquisition instruments. Users can create custom interfaces with spreadsheet packages such as Excel or Lotus 1-2-3 for Windows. The software supplies data in real time to the spreadsheet, which in turn graphically displays it in a choice of formats.
Circle Reader Action Number 796.



New on the Market

An advanced **composite filler** developed by Micro Composite Materials Corp., Research Triangle Park, NC, enhances physical properties in metal and ceramic matrices. The unique hollow titanium carbide microspheres have a 1-2 micron wall thickness and an average diameter of 20 microns. The microspheres have a relatively high hydrostatic crushing strength of 10-15 ksi, a melting point of 3140° C, chemical stability, and excellent wettability in Ti and Al matrices. They can significantly reduce structural weight in aerospace metal matrix composites while retaining high mechanical strength.
Circle Reader Action Number 780.

The first four-channel, 1-GSa/s **portable oscilloscope** is available from Hewlett-Packard Co., Palo Alto, CA. The HP 54512B oscilloscope samples 1 GSa/s on all four channels simultaneously, providing improved single-shot timing accuracy. Other features include 8-bit vertical resolution, 300-MHz repetitive bandwidth, and 8-k memory per channel.
Circle Reader Action Number 774.



Apex Microtechnology Corp., Tucson, AZ, has introduced a rugged **high-power amplifier** that combines thermal sensing on the output MOSFETs with four-wire current limiting. The combination of thermal protection, current limit, and a safe operating area free of second breakdown makes the new model PA05 well-suited for applications with demanding loads, such as reactive loads or motors. The amplifier also features a shutdown control that allows the output stage to be turned off for standby operation or load protection during fault conditions.
Circle Reader Action Number 776.

The industry's first **infrared thermocouple**, the IR t/c™ from Exergen Corp., Newton, MA, permits temperature control using an actual thermocouple—without surface contact. It combines the low cost of a standard thermocouple with the speed and versatility of a noncontact infrared sensing system. The IR t/c measures 1.75" long, .5" in diameter and has an accuracy of ±2% with ±1% repeatability.
Circle Reader Action Number 782.

Percept™ II **CAE software** from Sendrian Resources Corp., Newbury Park, CA, identifies design material incompatibilities that lead to corrosion and premature degradation and recommends design solutions. It can detect incompatibilities between metals, plastics, elastomers, composites, solvents, process fluids, fuels, lubricants, adhesives, ceramics, and coatings. A built-in expert system estimates material service lives as a function of service temperature.
Circle Reader Action Number 778.

The model V-301 **airborne video recorder** developed by Photo-Sonics Inc., Burbank, CA, offers high-resolution, direct recording from HUD cameras, infrared sensors, and multifunction displays. Selected for use on the F/A-18, the compact, lightweight V-301 recorder provides over 400 lines of resolution in both color and black and white recording and is backward-compatible to VHS. It enables direct recording of multiple line scan rate, features a comprehensive built-in test capability, and is compatible with both parallel and serial interfaces.
Circle Reader Action Number 784.

RF Inter-Science Co. Inc., Huntington, NY, has introduced the Macroscope LWD, an innovative long-working-distance **microscope**. At distances of 18 to 20 inches, it provides fixed wide-field magnifications of 7X, 12X, and 19X, and variable magnification of 9.5X to 27X. The microscope can be coupled to both video and 35 mm SLR cameras, and offers industrial and research applications in entomology, nuclear energy, chemistry, and other fields.
Circle Reader Action Number 786.

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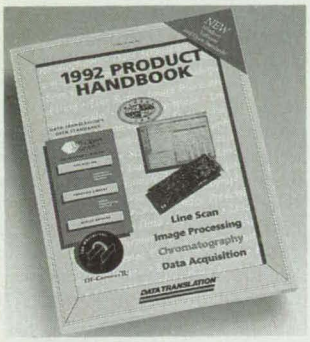
New Literature



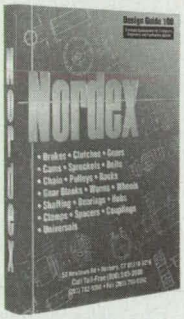
Data Translation, Marlboro, MA, has announced its 1992 product handbook describing **data acquisition, image processing, chromatography,** and **line scan** products for the IBM PC/XT/AT, IBM PS/2, Macintosh II, VMEbus, MicroVAX, and iSBX Bus. New products include the DT-Connect II open bus interface standard that provides direct 32-bit transfers at 100 MB/sec. between up to five boards. The handbook also details a new open software architecture, DT-Open Layers for Microsoft Windows, Windows Dynamic Link Libraries for developing applications, and the GLOBAL LAB image processing and data acquisition libraries.
Circle Reader Action Number 708.

Keithley Instruments Inc., Cleveland, OH, has released technical literature on **superconductivity research** instrumentation and techniques. Topics include automating resistance measurement on high-temperature superconductors, covering measurement techniques, system configuration, noise control, software, and resistivity measurement techniques. Tips on automating test procedures are included, with schematics and electrical connection diagrams for a variety of system setups.
Circle Reader Action Number 706.

Free literature describes **cooperative research** and **licensing opportunities** at Princeton University's Plasma Physics Laboratory. The lab has produced a wealth of inventions in such areas as neutral beam technology, remote handling of nuclear systems, plasma engineering and diagnostics, surface modification technology, magnetic field systems and analysis, and RF heating and current drive.
Circle Reader Action Number 712.

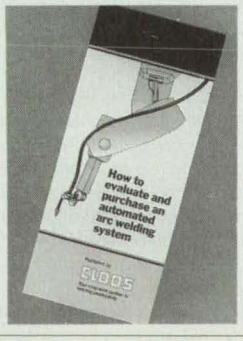
A design guide from Nook Industries Inc., Cleveland, OH, features ActionJac™ **metric power cylinders** and accessories. The publication provides detailed charts and technical data on motor selection, capacity, life expectancy, and maintenance.
Circle Reader Action Number 710.

A 528-page design guide published by Nordex Inc., Danbury, CT, offers a comprehensive list of components and assemblies for use in **precision electro-mechanical devices**. New items include variable durometer couplings, linear rotary bearings, telescopic universal joints, radial ball bearings, and metric dowel pins.
Circle Reader Action Number 714.



A 24-page guide from Shin-Etsu Polymer America Inc., Union City, CA, discusses factors to consider when designing or buying **silicone rubber** parts. The booklet describes the unique properties of silicone rubber and reviews five common fabrication techniques: compression, transfer, injection and liquid injection molding, and extrusion. Applications in aerospace, automotive, electronic, and medical products are illustrated.
Circle Reader Action Number 704.

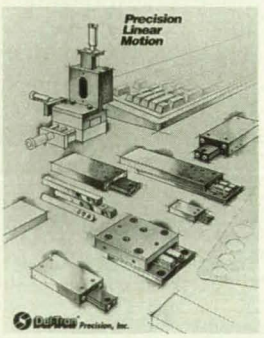
Cloos International, Elgin, IL, has published a checklist for selecting a **robotic arc welding system**. The pamphlet discusses whether an early return on investment is necessary, whether the system under consideration is an automatic solution to a welding need, whether the vendor provides technical assistance, and whether the supplier can demonstrate specific welding results.
Circle Reader Action Number 702.



New Literature

Cole-Parmer Instrument Co., Chicago, IL, has published a four-color catalog of **technical training materials**. It features sections on chemistry, computers, engineering, mathematics, quality control, software, statistics, safety, and audiovisual training aids. Titles include: *The Hazardous Chemicals Desk Reference, Chemical Technician's Ready Reference Guide, Laboratory Safety in Practice,* and *Quality Control Advisor.*
Circle Reader Action Number 718.

Del-Tron Precision Inc., Bethel, CT, has released a 40-page product guide describing **motion components** for precision linear motion. It highlights over 200 slide assemblies, including ball and crossed roller slides, aluminum and steel slide tables, and ball and crossed roller positioning slides. A handy selection guide helps the reader determine the correct slide for particular weight-carrying requirements.
Circle Reader Action Number 724.



A full-color brochure from Agema Infrared Systems, Secaucus, NJ, highlights new **infrared imaging and analysis systems** offering high thermal image resolution and data accuracy. The Thermovision® 900, designed for advanced research, incorporates an innovative facet-following scanning concept to increase efficiency by nearly 300% over conventional scanning systems. The second-generation 800 series is suited for use in applied industrial research and quality control. Both systems acquire and digitize a signal in 12 bits before transmission to ensure full dynamic signal range capture and storage.
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A brochure describes metallic and ceramic **coatings** for the aerospace, industrial gas turbine, medical, and other industries. Available from Howmet Corp., Greenwich, CT, the coatings extend the operating life of complex components by protecting them against extreme heat, corrosion, and abrasion. Howmet's facilities employ such advanced technologies as chemical vapor deposition and low-pressure plasma spraying.
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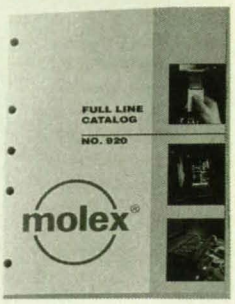

A 920-page catalog offered by Molex Inc., Lisle, IL, features fiber optic, telecom, and SIMM socket **interconnect products**. It illustrates more than 35,000 products, including ribbon cable systems, PCB interconnections, edge connectors, FFC connectors, sockets, pin and socket connectors, and I/O connectors.
Circle Reader Action Number 726.

A **die** data book from Semtech Corp., Corpus Christi, TX, provides electrical and mechanical specifications for designers of thick- and thin-film hybrid assemblies. The company manufactures switching regulators, linear regulators, rectifiers, pulse width modulators, and Darlington transistors, all available in die form.
Circle Reader Action Number 722.

Miller Thermal Inc., Appleton, WI, is offering two posters addressing **thermal spray** technology. One illustrates the various forms of thermal spray: plasma spray, arc spray, high-velocity oxygen fuel, powder flame spray, and wire or rod flame spray. The second is a spray coating selector guide that describes coating types, characteristics, and applications.
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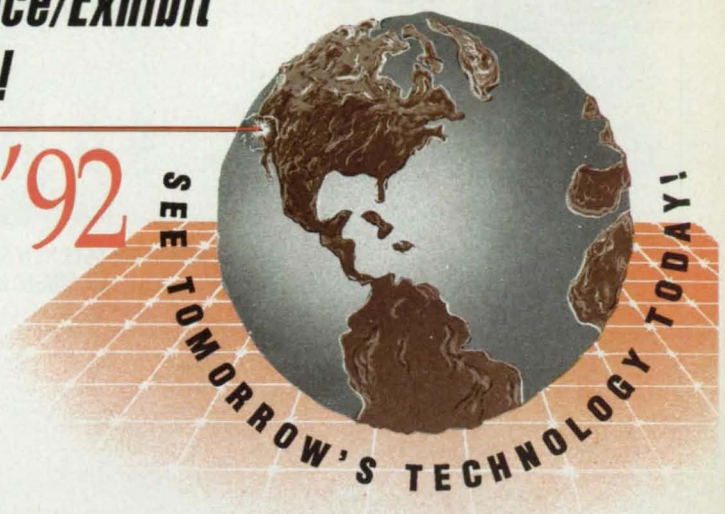

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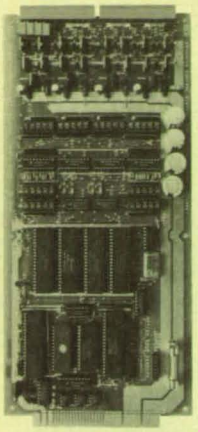

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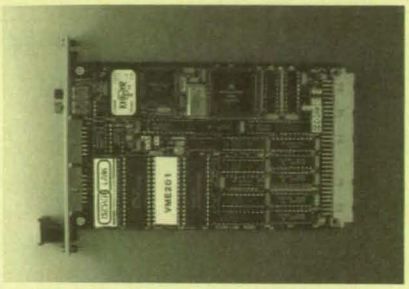

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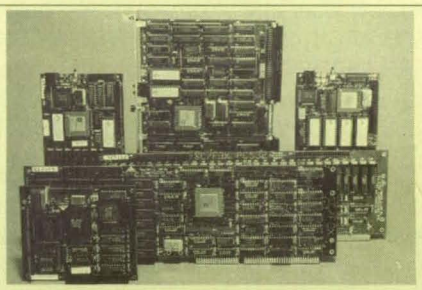

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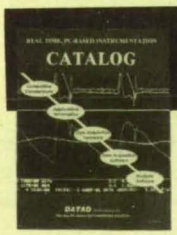

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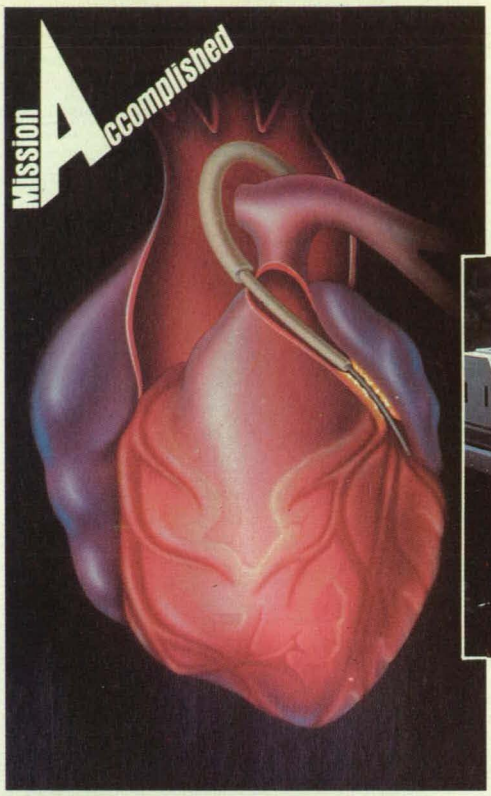
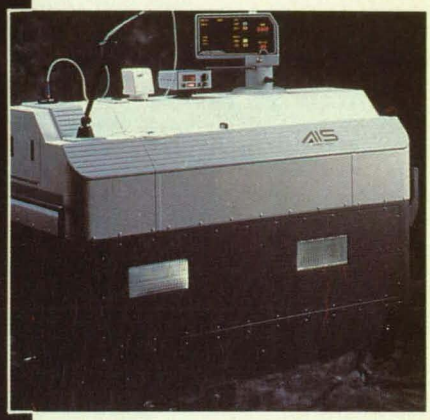


Illustration courtesy Advanced Interventional Systems Inc.

Through the technology transfer process, many of the systems, methods, and products pioneered by NASA are reapplied in the private sector, obviating duplicate research and making a broad range of new products and services available to the public.



The Dymer™ 200+ excimer laser angioplasty system (above) transmits a laser through a fiber optic catheter to vaporize the plaque clogging a coronary artery (left).

Physicians have a powerful new weapon in the war against heart disease, thanks to space technology.

A laser system first used for satellite-based atmospheric studies has been reapplied to treat atherosclerosis, the buildup of fatty deposits (called plaque) in the arteries that can lead to heart disease—the number one cause of death in the United States. Developed by Advanced Interventional Systems Inc. (AIS), Irvine, CA, the Dymer™ 200+ excimer laser angioplasty system vaporizes blockages in coronary arteries without damaging the arterial walls. In January, the system received FDA approval for treatment of coronary disease, specifically for lesions that are 20 mm or longer.

Laser angioplasty is less expensive and, because it is minimally invasive, less risky than a coronary bypass. Further, lasers can help a broader range of patients than the current bypass alternative, balloon angioplasty, which clinical data suggests is most successful in treating short, discrete lesions.

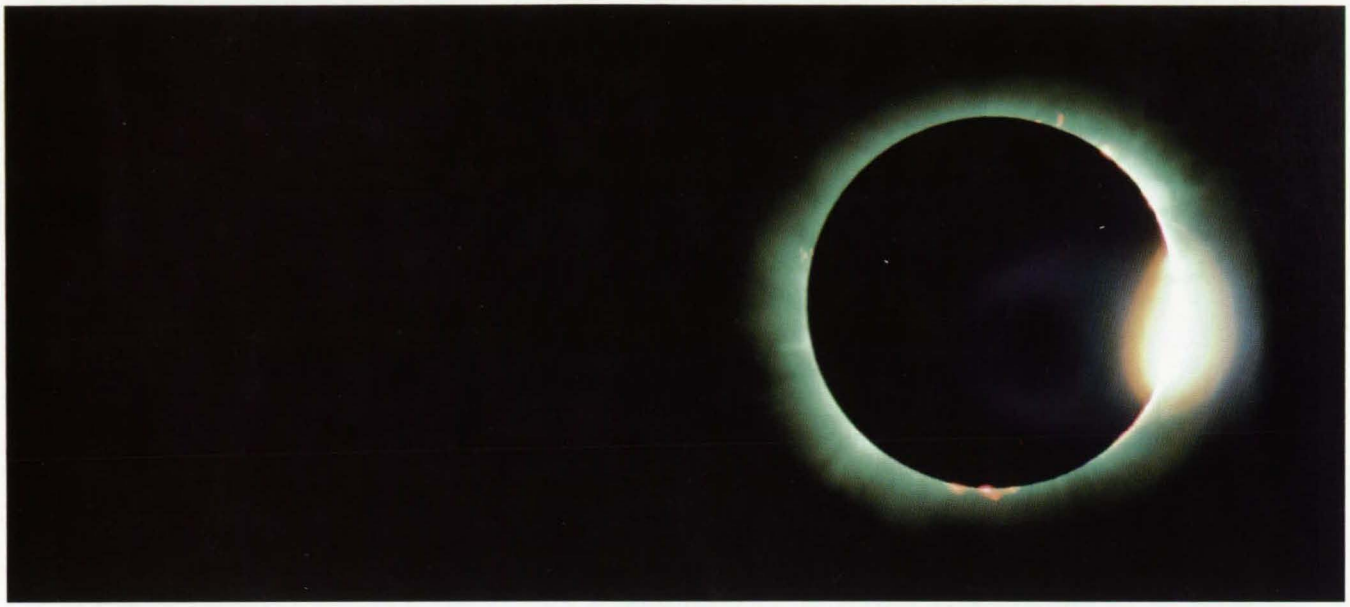
The AIS system employs excimer laser technology pioneered at NASA's Jet Propulsion Laboratory (JPL) for remote sensing of the ozone layer. While other types of lasers such as CO_2 and nd:YAG have surgical applications, they are too hot for delicate coronary surgery and could damage tissue, cause blood vessel spasms, or create blood clots. The excimer is a "cool" laser that uses ultraviolet light energy to operate at 65° C, a temperature human tissue can tolerate.

"Just as you wouldn't prescribe the same drug and dosage for every condition or person, you wouldn't use just one type of laser," said James Laudenslager, formerly director of JPL's Laser Physics and Applications Group and now vice president for laser development at AIS, which he co-founded in 1986.

Incorporating NASA-developed magnetic switching technology, the laser produces a uniform beam that can be controlled and pulsed in a period as little as 200 billionths of a second to maintain a low temperature. The laser light is carried through fiber optic bundles within a flexible catheter designed to navigate the most distal coronary anatomy.

Since clinical tests began in 1988, over 2000 coronary angioplasty procedures have been performed with the Dymer 200+ at 30 hospitals nationwide. It can be used to treat peripheral vascular disease, and may have applications in neurosurgery and orthopedics. The system earned AIS an award for excellence in technology transfer at last December's Technology 2001 conference in San Jose. ❑

For more information about excimer laser angioplasty, contact James Laudenslager, Advanced Interventional Systems Inc., 9 Parker, Irvine, CA, 92718.



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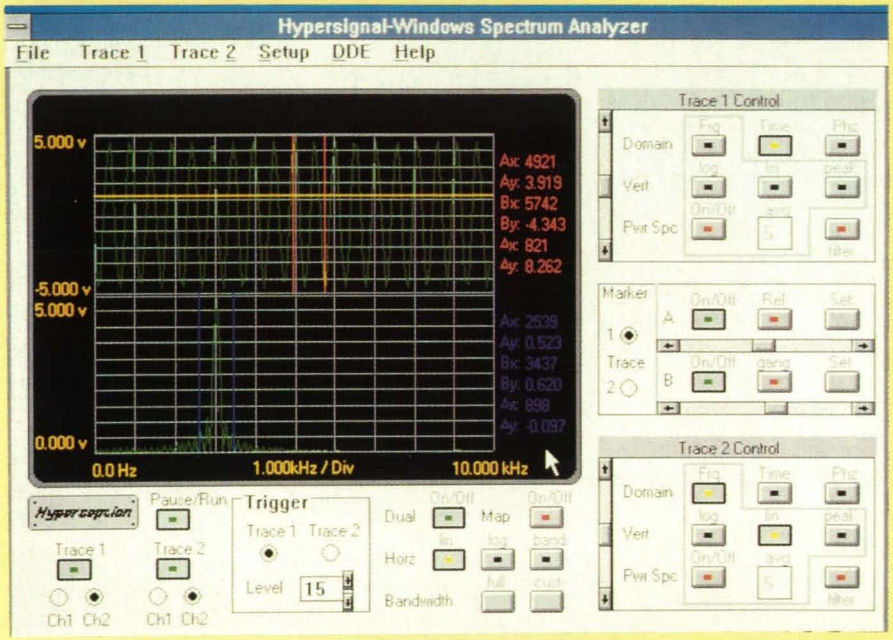

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